NUTRIENT REMOVAL FROM SECONDARY EFFLUENTS BY WATER HYACINTHS

A Thesis Submitted
in Partial Fulfilment of the Requirements
for the Degree of
MASTER OF TECHNOLOGY

By

ARUN KUMAR BANSAL

to the
DEPARTMENT OF CIVIL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY, KANPUR

OCTOBER, 1981

87477

CE-1981-M-BAN-NUT

In

Loving Memory

of

My Mother

POST GRADUATE OFFICE
Submitted on........

CERTIFICATE

Certified that the work presented in this thesis entitled "Nutrient Removal from Secondary Effluents by Water Hyacinths" by Mr. Arun Kumar Bansal has been carried out under our supervision and it has not been submitted elsewhere for a degree.

Dr. A.V.S. Prabhakara Rao
Co-supervisor
Professor
Civil Engineering Department
Indian Institute of Technology
Kanpur

Late Dr. S.D. Bokil
Thesis Supervisor
Assistant Professor
Civil Engineering Department
Indian Institute of Technology
Kanpur

October, 1981.

POST GRADUATE OFFICE
This thesis has been approved
for the award [illegible] Degree of
Master [illegible] (M.Tech.)
in [illegible]
regu[illegible]
Institute [illegible] Kanpur
Dated. 2/11/81

Name of Student	:	ARUN KUMAR BANSAL
Department	:	Civil Engineering
Programme	:	M.Tech.
Title of Thesis	:	Nutrient Removal from Secondary Effluents by Water Hyacinths
Thesis Supervisors	:	Late Dr. S.D. Bokil and Dr. A.V.S. Prabhakara Rao

ABSTRACT

A survey of the literature revealed that studies on water hyacinths as a final filteration system for reducing nutrients budget of secondary effluents, are very few. The objective of this investigation was, therefore, to develop a hyacinths system to act as a polishing unit for secondary effluents based on laboratory scale batch studies.

Response of hyacinths to various concentrations of different parameters, viz., Urea-N, Ammonia-N, Nitrate-N and Phosphate-P was evaluated as an initial step towards the development of such a system. The removal efficiencies of Urea-N, NH_3-N, NO_3-N and PO_4-P were found to be independent of their initial concentrations upto the values of 25, 20, 20 and 25 mg/l respectively. Any concentration of NH_3-N higher than 50 mg/l caused toxicity to the plants. From the study on three feed N:P ratios of 3:1, 3.5:1 and 4:1, nitrogen uptake was found to be 3.4 to 4.4 times higher than that of phosphorous. The nutrient removal efficiency during night hours was significantly reduced.

By observing the effect of various mean operational water depths of hyacinths basin on phosphorous removal efficiency, it was concluded that the phosphorous uptake with respect to that

of control unit decreased with increase in mean operational water depth.

A preliminary model was formulated to describe the relationship between mean operational water depth of basin and detention time correlating with percent phosphorous removal. It was used as a tool for estimating the optimum mean operational water depth of 1.7 m, by minimizing the objective function i.e. cost of the basin. It was further noted that water hyacinth plants could consume 90 percent phosphorus from the basin with mean operational water depth of 1.7 m at a detention time of 11.5 days with a ratio of 1.33:1 between plan surface areas of basin and hyacinth plants.

ACKNOWLEDGEMENT

I remember Dr. S.D. Bokil for his able guidance, love and affection.

I am deeply indebted to Dr. A.V.S. Prabhakara Rao for his active interest, moral support and constant encouragement throughout the present work.

I take this opportunity to express my gratitudes to Dr. M. Chaudhuri, Dr. C. Venkobachar, Prof. D.K. Ghosh and Dr. I.C. Agarwal for their kind advices and suggestions during the study.

My sincere thanks are extended to Dr. (Mrs.) Leela Iyengar for her active co-operation.

I am extremely thankful to Mr. V. Tare and Ms. Madhu Sharma for their deep involvement, which needs a special mention.

I acknowledge the kind helps of Dr. S.P. Srivastava and Ms. Usha Jauhary during literature survey.

It is with grateful appreciation that I acknowledge the assistance of my friends Messrs P. Deva, A.K. Bhattacharya, D.S. Ray, S.P. Sharma and Dr. (Ms.) V. Lakshmi and all other members of Environmental Engineering family.

My special thanks are due to Sri R.C. Adhikari for his exceptional contribution at all the levels during the study.

I acknowledge the help of Messrs S.N. Misra, N.R. Sahu and Vijay.

I must mention the names of Sri A.K. Gupta and Sri M.K. Srivastava to complete the list, if at all it is possible.

A.K. Bansal

CONTENTS

		Page
1.	INTRODUCTION	1
2.	LITERATURE REVIEW	3
	2.1 Characteristics of Secondary Effluents	3
	2.2 Nutrient Removal Techniques	4
	2.3 Water Hyacinth (Eichhornia crassipes)	6
	2.3.1 History	6
	2.3.2 Classification and Nature of Plants	6
	2.3.3 Morphology	6
	2.3.4 Evapotranspiration	7
	2.3.5 Propagation of Water Hyacinth	7
	2.3.5.1 Factors Affecting the Growth of Water Hyacinth	8
	2.3.6 Utilization of Water Hyacinth	9
	2.3.6.1 Pollution Abatement	9
	2.3.6.2 Biogas Production	11
	2.3.6.3 Use as a Fertilizer and Compost	12
	2.3.6.4 Use as a Protein Source	12
	2.3.6.5 Pulp Paper and Fibre	12
3.	SCOPE OF INVESTIGATION	13
4.	MATERIALS AND METHODS	15
	4.1 Materials	15
	4.1.1 Water Hyacinth Plants	15
	4.1.2 Feed Solutions	15
	4.2 Methods	15
	4.2.1 Experimental Techniques	15
	4.2.1.1 Production of Water Hyacinth Culture	15
	4.2.1.2 Phase 1 Studies	18
	4.2.1.3 Phase 2 Studies	18
	4.2.2 Analytical Techniques	19
	4.2.2.1 Instruments	19
	4.2.2.2 Sampling	19
	4.2.2.3 Analyses	20
5.	RESULTS AND DISCUSSIONS	22
	5.1 Phase 1 Studies	22
	5.1.1 Phase 1A Studies	22
	5.1.2 Phase 1B Studies	31
	5.2 Phase 2 Studies	38
	5.3 Phase 3 Studies	41
	5.3.1 Harvesting of Hyacinths	48
	5.3.2 Limitations of the Proposed Hyacinths System	50

	Page
6. CONCLUSIONS	51
7. RECOMMENDATIONS FOR FUTURE RESEARCH	53
REFERENCES	54
APPENDIX	58

LIST OF TABLES

Table		Page
2.1	Effluent characteristics from various biological processes	3
4.1	Characteristics of feed solutions containg one parameter only	16
4.2	Characteristics of feed solutions combining all the parameters	17
5.1	Characteristics of feed solutions used in Phase 1B studies	31
5.2	Computed values of K, R and S	45

LIST OF FIGURES

No.		Page
5.1	Response of hyacinths to various concentrations of urea-nitrogen	23
5.2	Response of hyacinths to various concentrations of ammonia-nitrogen	26
5.3	Variation in ammonia uptake with its different concentrations	27
5.4	Response of hyacinths to various concentrations of nitrate-nitrogen	29
5.5	Response of hyacinths to various concentrations of phosphate-phosphorous	30
5.6	Removal of nitrogen and phosphorous from feed N:P ratio of 3:1	33
5.7	Removal of nitrogen and phosphorous from feed N:P ratio of 3.5:1	34
5.8	Removal of nitrogen and phosphorous from feed N:P ratio of 4:1	35
5.9	Temporal variation of nitrogen and phosphorous uptake by hyacinths with various feed N:P ratios	37
5.10	Removal of phosphorous with various mean operational water depths	39
5.11	Variation in detention time with different mean operational water depths for certain percent removal of phosphorous	44
5.12	A model system for secondary effluent treatment using water hyacinths and subsequent utilization of harvested hyacinths plants	49

1. INTRODUCTION

It has become apparent over the past several years that achievement of high levels of water quality demanded by progressive water use and reuse requirements necessiate expanded utilization of advanced technologies for wastewater treatment. Conventional secondary biological treatment processes, previously considered 'complete', do not provide the required degree of treatment for protecting natural waters from pollution.

Conventional secondary treatment processes result in effluents which are rich in inorganic nutrients e.g. nitrogen and phosphorus. This nutritious nature of secondary effluents may create the problem of turning over the oligotrophic nature of receiving waters to an eutrophic one (Lackey, 1958). Nitrogen in any form added to the surface waters stimulates undesirable growth of algae, mosses and aquatic weeds. The growth of algal blooms in excess impart an unaesthetic sense and create problems in receiving waters. Nuisance conditions like fish kill, odour and taste are several other associated problems. If nitrate is also present in the effluents, it may be a contributing factor or, perhaps, the main cause of methemoglobinemia in infants (Stewart, 1968). Urea is in itself not toxic, however, it is readily hydrolysed to produce free ammonia in natural waters and hence the danger to normal fish population.

Therefore, lessening of nutrients budget of secondary effluents seems to be a matter of utmost importance. As a

result, the expressed concern of regulatory agencies, self interest group, scientists and engineers have made several efforts in this direction.

Water Hyacinth (Eichhornia crassipes), an aquatic plant, has been proposed by several investigators as an effective agent to absorb nutrients. Though, sufficient literature is available on its purifying capability, very few studies have been undertaken to evaluate the effect of several important parameters such as nutrient concentrations, mean operational water depth of hyacinths basin and nature of feed which may have significant influence on achieving quick and lasting treatment. The present work has, therefore, been devoted to study the response of hyacinth plants to various concentrations of nitrogen and phosphorous, effects of different mean operational water depths of hyacinths pond on nutrient removal efficiencies and to lay down the design criteria for such a system based on laboratory scale batch studies.

2. LITERATURE REVIEW

With proper analysis and environmental control, almost all wastewaters can be treated biologically. The biological treatment processes do not prevent nutrient enrichment of receiving waters, because they remove only a fraction of carbon and soluble components like nitrogen and phosphorous.

2.1 Characteristics of Secondary Effluents:

Many of the pollutants found in wastewaters are not adequately removed by conventional secondary treatment processes. These pollutants may include soluble inorganic compounds such as phosphorus and/or nitrogen, higher complex synthetic organic compounds, colour, taste, odour, and colloidal solids (Culp et.al., 1978). The general characteristics of effluents from various biological treatment processes are presented in Table 2.1 (Metcalf et.al., 1979).

Table 2.1 : Effluent characteristics from various biological processes

Secondary treatment	Typical secondary effluent quality						
	Suspended solids mg/l	BOD mg/l	COD mg/l	Total N mg/l	PO_4 as P mg/l	Turbidity mg/l	Colour units
Activated-sludge process	20-30	15-25	40-80	20-60	6-15	5-15	15-80
Land treatment	<1	≤ 2	-	3	0.3		
Trickling-filter process	20-40	15-35	40-100	20-60	6-15	5-15	15-80

Generally, secondary effluents contain two to four times as much nitrogen as phosphorus (Gakstatter et.al., 1978). Thus, secondary biological treatment processes are not capable of preventing the water enrichment and other associated problems.

2.2 Nutrient Removal Techniques:

Various techniques have been proposed and tried for nutrient removal from secondary effluents. However, only few are found to be successful in the field. This might be either due to prohibitive cost of installation and operation or due to inefficient working or other inherent defects. Besides the physicochemical processes, the methods presently available are Break point chlorination, Ion exchange process, Air stripping, Biochemical nitrification-denitrification, Harvesting of algae and Land disposal.

Bhattacharrya et.al. (1973) observed that upto 10 mg of chlorine is required for reacting 1.0 mg/l of Ammonia-N. High chlorine demand is the major limiting factor for the use of break point chlorination.

Mercer et.al. (1970) obtained 90 percent removal with selective ion exchange process while treating clarified secondary effluent containing 10-19 mg/l Ammonia-N. On the other hand, Cousins et.al. (1972) from their study on tertiary treatment of weak Ammonia-N liquor concluded that hydrogen ion exchange is impractical because of resin fouling.

From the comprehensive study on removal of Ammonia-N from nitrogeneous waste, Bhalerao et.al. (1973) reported that air stripping works out to be the costliest of the methods tried.

Biochemical nitrification-denitrification process is very complex and sensitive to several physical and chemical factors. The principles involved in this method are to convert ammonia into nitrites and nitrates by highly specific group of aerobic, autotrophic bacteria and then converting nitrates by another group of anaerobic bacteria into gaseous nitrogen products (Haug et.al., 1972). These nitrifying organisms are very sensitive to environmental conditions such as pH, temperature, dissolved oxygen concentration and organic substances, which in turn make the process sensitive.

Gates et.al. (1964) have reported 98 percent and 92 percent removal of nitrogen and phosphorus respectively by harvesting algal culture in experimental ponds. Betzer et.al. (1980) have also demonstrated the significant removal of nitrogen and phosphorus by algal recovery by ozone induced floatation. However, harvesting of algae itself is a tedious and expensive process.

In the developing countries like India, land disposal, the practice of disposing of sewage and/or secondary effluents in the earth's soils metal, instead of its surface waters has received a great deal of publicity over the past few years. The system acts as complex, mixed media filter (Young et.al., 1975). According to Michal et.al. (1974) the choice of the system depends largely on topography, soils and sub-soils condition, vegetative cover, ground water levels and water quality protection requirements. Wolmann (1977) traced the history, development and philosophy of land application and

concluded that it must be evaluated on a case by case basis and monitoring of land application is required to prevent undue hazard to ground water or drainage effluent.

2.3 Water Hyacinth (Eichhornia Crossipes):

2.3.1 History:

A native of Brazil, water hyacinth has now widely distributed throughout the world in tropics and subtropics (Evans, 1963). There are no definite reports of the time of its entry into India but it had definitely arrived in India before 1900. According to Biswas et.al. (1954) the weed got established in Bengal near about 1896 and in a span of 85 years weed has established itself throughout the country.

2.3.2 Classification and Nature of Plants:

Water hyacinths are large, floating, vascular aquatic plants and belong to a family pontedariaceae placed under the order Lilials (Holm et.al., 1969). The plants live on the surface of water and grow without the necessity of any attachment to soil. Water hyacinth plants are generally found in ponds, lakes, pools, tanks, reservoirs, streams, rivers and in irrigation channels (Evans, 1963).

2.3.3 Morphology:

The plant is a free floating stoloniferous herb. It consists of a rhizomotous stem, a rosette of leaves and numerous pendulus roots (Gopal et.al., 1981). The stem or the rhizome consists of an axis with several internodes which bear the leaves, roots offshoots and inflorescence. The

elongated internodes are stolen. The leaves are bright green, shinny and consists of liqule, a spongy float, an isthmus and because the leaves are upright, serve as soils before the wind (Gopal et.al., 1981).

2.3.4 Evapotranspiration:

A number of experimental studies have shown that the water loss through evapotranspiration from water hyacinths mat exceeds the loss from open water surface. According to Weert et.al. (1974) evapotranspiration loss is 44 to 40 percent higher than free water evaporation. Evans (1963) concluded that in the dry atmosphere of India, the loss of water through water hyacinth is 7-8 times that of open water surface.

2.3.5 Propagation of Water Hyacinth:

Water hyacinth has tremendous capacity to grow and regenerate. It propagates both by seed germination and by vegetative means (Wolverton, 1975a). The vegetative growth is very rapid. Several workers have recorded interesting figures of its growth rate. Holm et.al. (1969) observed 30 offsprings from two parent plants in 23 days, and 1200 at the end of four months. Wolverton et.al. (1975c) reported an increase in hyacinths surface area by 6 to 10 percent per day. Bock (1969) suggested that the rate of mean daily increment by vegetative means can be calculated by the equation

$$N_o\, X^t = N_t$$

where

N_o is the number of plants growing at a certain time;

X is the geometric rate of daily increment;

t is the time in days;

and N_t is the number of plants after time t.

In other studies, the growth rate has been expressed in terms of Relative Growth Rate (RGR) and Doubling Time (DT) following the formulae noted below (Gopal et.al., 1981).

$$RGR = \frac{\ln X_t - \ln X_o}{t}$$

$$DT = \frac{\ln 2}{RGR}$$

where

X_o is the initial weight of the plants;

and X_t is the weight of plants after time t.

2.3.5.1 Factors Affecting the Growth of Water Hyacinth:

Several studies have shown the effect of different environmental factors on the growth of water hyacinth plants.

(i) Light: The plant can grow under a wide range of light intensities. The total light requirement is equivalent to 240,000 lux-hours for optimum growth and a minimum light requirement of 24,000 lux-hours (Gopal et.al., 1981).

(ii) Temperature: The optimum temperature requirement of the plants is 27-30°C (Gopal et.al., 1981). The plants do not withstand temperature higher than 40°C. The

plants die within hours when the surface water temperature approaches the freezing point (Dinges, 1978).

(iii) Nutrients: In different studies different concentrations of N and P have found to result in optimum growth. It is reported that the critical level of phosphorus and nitrogen for growth is 0.1 and 2.5 mg/l respectively (Gopal et.al., 1981).

(iv) pH: Parija (1934) observed that the optimum growth of water hyacinth plants occurs at pH 6 to 9. At low or high pH the growth is checked but the plant is not killed.

2.3.6 Utilization of Water Hyacinth:

Despite several efforts with different control measures and heavy expenditure, man has had hardly any success in controlling the weed, much less to talk of its eradication. This failure coupled with the growing need to search alternative resources for various purposes, turned the attention towards finding ways and means for utilizing water hyacinth. Cursed for so many years, the water hyacinth is now beginning to gain respectability by offering relatively simple and economically attractive solutions to some of mankind's most pressing problems (Wolverton et.al., 1976a). The uses of this plant represent a wide spectrum. Brief account of the most important uses are given below.

2.3.6.1 Pollution Abatement:

One of the most serious problems faced by man today is that of water pollution. Several studies in the

laboratory as well as in field have indicated that aquatic plants in general and water hyacinth in particular, can fight this problem due to their ability to absorb various pollutants in large quantities from wastewater. Vascular aquatic plants such as water hyacinth, when utilized in biological system may represent a remarkably efficient and inexpensive filteration and disposal system for toxic materials and sewage released into waters near urban and industrial area (Wolverton et.al., 1975c).

The city of Austin, Texas, for instance, has provided facilities at its Williamson Creek Wastewater Treatment for evaluation studies. On feasibility of employing aquatic plants to facilitate further reduction of undesirable suspended and dissolved substances from water (Dinges, 1976). From his study using water hyacinths as a polishing unit for stabilization pond effluents, Dinges (1978) reported that at a flow rate of 1.26 l/sec, detention time 5.3 days and operational mean water depth of 85 cm, the mean percent reduction in volatile suspended solids, total coliform/100 ml, BOD_5, COD and total nitrogen were 93, 82, 87, 72 and 63 percent respectively. Wolverton et.al. (1979) have also observed that water hyacinth may be a highly effective means to upgrade the facultative lagoons. Field tests using water hyacinth as biological filteration agent to treat the effluent from Bay St. Louis Lagoon System, shows the ability to maintain BOD_5 and TSS levels within the Environmental Protection Agency's prescribed limit (Wolverton et.al., 1976b).

The water hyacinth may be used as a practical means of eliminating nitrogen and phosphorus before they are effluented into water course (Ramachandran et.al., 1971). According to Dunigan et.al. (1975) the uptake rate of Ammonia-N by water hyacinth is maximum and phosphate-P is minimum. Corwell et.al. (1977) also observed the nutrient removal capabilities of water hyacinth growing in a secondary effluent polishing pond. They (Corwell et.al., 1977) reported that the percent reduction in turbidity, total Kjeldahal-N, Ammonia-N, Nitrate-N, Phosphate-P was 26.8, 8.54, 7.43, 2 and 5.7 respectively.

The most remarkable feature of water hyacinth is its capability to accumulate heavy metals. It can absorb and concentrate upto 0.67 mg of cadmium, 0.5 mg of nickle, 6.175 mg of lead, 0.15 mg of mercury, 0.439 mg of silver, 0.568 mg of cobalt and 0.543 mg of strontium in an ionized form per gram of dry plant material in 24 hours (Wolverton, 1975a, Wolverton et.al., 1975b, d).

2.3.6.2 Biogas Production:

Water hyacinth can be successfully used for production of biogas which is now considered to be a viable alternative to petroleum and natural gases. Wolverton et.al. (1975c) reported that an average of 13.9 ml of methane gas per gram of wet plants can be produced by microbial fermentation of hyacinths. According to Sharma (1971) 26,500 ft^3 of biogas containing 80 percent methane gas is obtained from the bacterial fermentation of these plants. Cost of gas generation from the hyacinths is also very less. Sriramulu et.al. (1980)

showed that 5 m^3 of biogas can be generated per day at a cost of Rs. 11.75 only.

2.3.6.3 Use as a Fertilizer and Compost:

Water hyacinth .. meal is a good source of organic fertilizer and soil conditioner. The plant contains approximately, organic matter 75, nitrogen 15, ash 24.2 percent and ash is found to have potassium oxide 28.7, sodium oxide 1.8, calcium oxide 12.8 and phosphorus pentaoxide 7 percent (Sharma, 1971). These figures show that the plant has a rather high NPK content. However, one has to be cautious enough not to use hyacinths containing toxic substances for this purpose as the soil will get polluted.

2.3.6.4 Use as Protein Source:

In search of suitable source of green leaves for bulk extraction of protein, water hyacinth was selected because of its availability. The work of Dutta et.al. (1966) indicated that leaves of water hyacinth contain about 20 percent on dry weight basis. This protein is better nutritionally than many other seed proteins (Pirie, 1966).

2.3.6.5 Pulp Paper and Fibre:

Water hyacinth has also found use in producing fibres and pulp for paper. The Regional Research Laboratory (RRL) in **Hyderabad** carried out special studies on the hyacinth plants and found that it can produce good quality paper and board (Jatkar, 1981).

3. SCOPE OF INVESTIGATION

From the review of literature, it can be seen that attempts have been made to cover a wide range of nutrient removal methods from chemical precipitation to sophisticated instrumentation, unsuited to Indian conditions. Land disposal technique, ofcourse is getting popularity in India. However, this method has got its own limitations, as indicated in Chapter 2.

The basic motive behind the present study is to contribute towards the development of a simple inexpensive nutrient removal system which is suitable perfectly for Indian conditions.

The use of water hyacinth, the most researched aquatic plant to date, as nutrient removal agent is not a new concept. Studies have shown high potential for adopting this system as a means of removal of nutrients from secondary effluents. However, after reviewing the relevant literature, it became apparent that parameters necessary for proper evaluation and potential design criteria for a nutrient removal system using water hyacinths grown in secondary effluents, were not available.

The ultimate objective of the present study, therefore, is to lay down the design criteria for secondary effluent treatment with hyacinth system from laboratory scale batch studies, by accounting the factors which govern the working of such a system. The proposed work was undertaken along the following lines.

(i) Phase 1 Studies:

Table 2.1 highlights the fact that nutrients budget in secondary effluents varies to a wide range. To reach a safer side, while designing a hyacinths system, it seems to be of great importance to evaluate the variations, if any, in nutrients removal efficiencies with their different concentrations. Hence, these studies were planned to investigate the response of water hyacinths to various concentrations of nutrients, viz., nitrogen and phosphorus. Different concentrations of nitrogen as well as phosphorus in reactors were exposed to the equal amount of the plants for same detention time and removal efficiencies with respect to each choosen parameter were observed.

(ii) Phase 2 Studies:

Depth, detention time and surface area of hyacinths basin are seemed to be the governing parameters of its extent of removal efficiency. In this phase of the study, it was decided, therefore, to indicate the effect on nutrient removal efficiencies with varying mean water depth of hyacinth basin by keeping its surface area constant.

(iii) Phase 3 Studies:

These studies were carried out to find out the design parameters on the basis of above studies. In order to determine the design parameters of nutrient removal system using water hyacinths, the relationship between detention time and mean water depth of hyacinths basin was established, and is correlated with the percent nutrient removal. The optimum depth of basin was also worked out by minimizing the cost of the hyacinth basin.

4. MATERIALS AND METHODS

4.1 Materials:

4.1.1 Water Hyacinth Plants:

Water hyacinth (*Eichhornia crassipes*) plants, grown in a natural depression adjacent to G.T. Road, near I.I.T. Kanpur gate, were chosen as a parent source. The plants were harvested and transported to the laboratory scale tank of size 200 cm x 150 cm x 30 cm, filled with tap water in which they propagated and multiplied by vegetative means under natural conditions. The pH of tank water ranged from 7.8 to 8.3 and temperature varied from 20 to 35°C during this study.

4.1.2 Feed Solutions:

Feed solutions used in this study were having different concentrations of parameters (Urea-N, NH_3-N, NO_3-N and PO_4-P), chosen in accordance to the nutritious characteristics of oxidation pond effluent obtained by Bokil (1968). Two types of feed solutions were prepared. One was containing only one parameter and other combining all the parameters. The characteristics of these feed solutions are presented in Tables 4.1 and 4.2 respectively.

4.2 Methods:

4.2.1 Experimental Techniques:

4.2.1.1 Production of Water Hyacinth Culture:

The plants were grown in laboratory tank under natural conditions. For the proper growth of the plants,

Table 4.1 : Characteristics of feed solutions containing one parameter only

Feed solution	pH	COD (Glucose as source) mg/l	Parameter	Source	Concentration, mg/l						
					Reactor						
					1	2	3	4	5	6	7
a	8.2	60	Urea-N	Urea ($CO(NH_2)_2$)	20	25	30	40			
b	8.2	60	Ammonia-N	Ammonium chloride (NH_4Cl)	10	15	20	25	30	50	70
c	8.2	60	Nitrate-N	Potassium nitrate (KNO_3)	10	15	20	25			
d	8.2	60	Phosphate-P	Potassium dihydrogen phosphate (KH_2PO_4)	15	20	25	30			

Table 4.2 : Characteristics of feed solutions combining all the parameters

Feed solution	pH	Reactor	COD mg/l	Parameter	Source	Concentration of parameter mg/l	N:P ratio
A	8.5	1	60	Urea-N	Urea	25	3:1
				Ammonia-N	Ammonium chloride	15	
				Nitrate-N	Potassium nitrate	5	
				Phosphate-P	Potassium dihydrogen phosphate	15	
B	9.0	2	60	Urea-N	Urea	40	3.5:1
				Ammonia-N	Ammonium chloride	25	
				Nitrate-N	Potassium nitrate	5	
				Phosphate-P	Potassium dihydrogen phosphate	20	
C	8.0	3	60	Urea-N	Urea	35	4:1
				Ammonia-N	Ammonium chloride	20	
				Nitrate-N	Potassium nitrate	5	
				Phosphate-P	Potassium dihydrogen phosphate	15	

the concentrations of nitrogen and phosphorus were maintained at or above their critical level as given by Gopal et.al. (1981).

4.2.1.2 Phase 1 Studies:

The plastic tubs of 25 liters capacity each and circular in plan were used. Best possible efforts were made to select the plants of equal age and size for all the experiments. The equal amount of plants weighing 160 grams wet along with 20 liters of feed solutions were introduced to all the reactors. In addition, a control test free of plants was also run for each reactor. During the experiment, tap water was added to compensate the loss of water because of transpiration and evaporation. This phase had two subphases, viz., Phase 1A and Phase 1B.

(i) Phase 1A Studies:

To study the effect of Urea-N, Ammonia-N, Nitrate-N and Phosphate-P separately, feed solutions a, b, c and d respectively (Table 4.1) were added to different reactors containing hyacinth plants. The content of all these parameters (i.e., Urea-N, NH_3-N, NO_3-N, PO_4-P) was monitored at different intervals.

(ii) Phase 1B Studies:

Reactors 1, 2 and 3 were filled with solution – A, B and C (Table 4.2) and the experiment was carried out exactly in a similar way as described above.

4.2.1.3 Phase 2 Studies:

A laboratory scale pond made up of 18 gauge galvanized iron sheets was used. The size of the tank

being 107 cm long, 53.5 cm wide and 76.2 cm deep, giving a surface area of 5724.5 cm^2 (= 0.57 m^2). A manometer to indicate the feed level in the pond was also fitted at the bottom of the tank.

Feed solution B (Table 4.2) was used for these studies. Various mean operational feed depths chosen were 30, 40, 50, 60 and 70 cm. The same amount of plants i.e., 1200 grams wet was used for each depth. Approximately 75 percent of pond surface area was covered with hyacinths. The feed level in the pond was kept constant with the help of manometer during the course of all the experiments. The phosphate-P was measured at different intervals.

4.2.2 Analytical Techniques:

4.2.2.1 Instruments:

The instruments used in the various analyses are listed below. Common instruments are not included in the list.

1. Centrifuge: SS-3, Sorvail
2. pH meter: Type 331, Cystronics
3. Spectrophotometer: Type 105, Cystronics

4.2.2.2 Sampling:

30 ml of sample was drawn every time using a pippettefrom a point one-third the water depth from the bottom. However, to ascertain the variation in results, samples were also collected from different points and from different depths.

4.2.2.3 Analysis:

The parameters used in this study are mentioned below along with various analytical methods to determine them.

(i) Urea-N: A direct spectrophotometric analyses was adopted to measure the concentration of urea in the solution (Charbit, 1966). A sample volume of 3 ml was taken in which 1 ml of colouring reagent (8.5 grams p-dimethyl amino benzaldehyde, 60 ml acitic acid, 10 ml hydrochloric acid and 3 ml distilled water) was added. The volume was made up to 5 ml with distilled water and absorbance was recorded at 440 nm and light path of 1.875 cm after 10 minutes.

(ii) Ammonia-N: Direct Nesselerisation method as given in Standard Methods (1965) was used for the measurement of Ammonia-N. Ammonium chloride was used for preparing the standard curve. Wave length of 440 nm with light path of 1.875 cm was used for ammonia determination.

(iii) Nitrate-N: Brucine method as given in Standard Methods (1965) was adopted for the determination of nitrate. A wave length of 440 nm at a light path of 1.875 cm was adopted. Potassium nitrate was used for preparing standard curve.

(iv) Phosphate-P: Phosphorus determination was done by the modified method of Tauskey and Shorr as given by Warton *et.al.* (1972). Standard curve was prepared

with potassium dihydrogen phosphate as standard. A wave length of 660 nm at a light path of 1.875 cm was adopted.

(v) pH: pH was measured by using the pH meter after calibrating the same with a buffer of known pH.

5. RESULTS AND DISCUSSIONS

The present study was conducted in three different phases and all the phases consist of batch studies. The studies are basically confined to the development of water hyacinths system for the removal of nitrogen and phosphorus from secondary effluents. The results obtained in these phases of the study are presented and discussed separately.

5.1 Phase 1 Studies:

As an initial step towards developing an efficient hyacinths system for removal of nitrogen and phosphorus from secondary effluents, which in turn depends upon the response of hyacinths to these nutrients, water hyacinths were exposed to different concentrations of Urea-N, Ammonia-N, Nitrate-N and Phosphate-P. To facilitate the representation, the results of this phase are discussed in two sections.

5.1.1 Phase 1A Studies:

These studies were carried out in order to evaluate individually the effects of different concentrations of Urea-N, Ammonia-N, Nitrate-N and Phosphate-P on hyacinth plants.

(i) Response of hyacinths to Urea-N:

The feed solutions having 20, 25, 30 and 40 mg/l of Urea-N were introduced to Reactors 1, 2, 3 and 4 respectively. The initial pH was 8.2. Fig. 5.1 demonstrates the capability of water hyacinths to absorb Urea-N from feed solutions. The

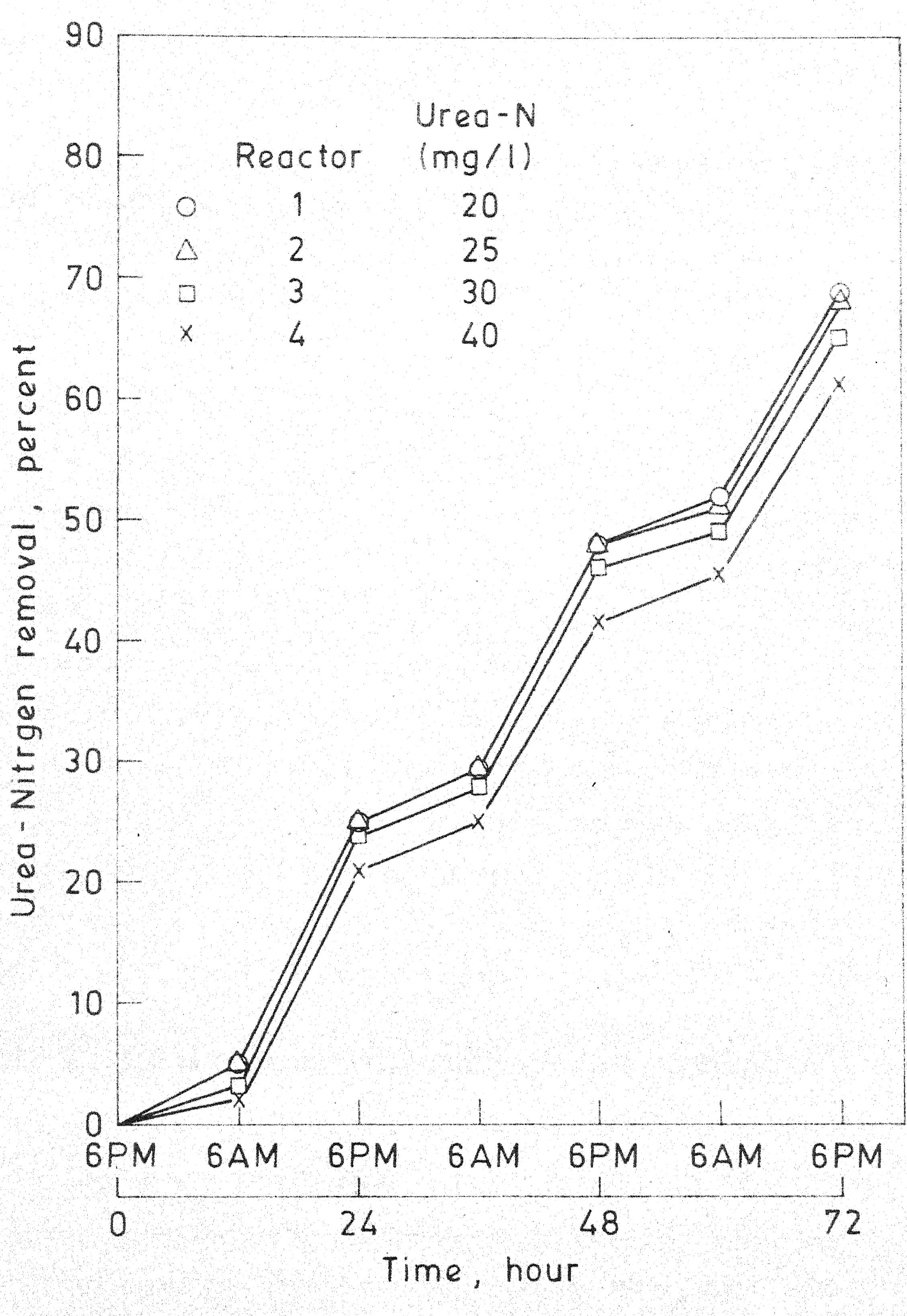

Fig. 5.1 - Response of hyacinths to various concentrations of Urea-Nitrogen.

percent reductions in Urea-N of Reactors 1 and 2 are not differing much at any time. With a detention time of 3 days, percent reductions in Urea-N content of Reactors 1 and 2 were 68 and 67 percent respectively. As the feed Urea-N concentrations increased beyond 25 mg/l, the corresponding removal efficiencies are decreased. In 3 days period removal of Urea-N varies between 65 percent in Reactor 3 and 61 percent in Reactor 4. Hence, it can be concluded that percent removal of Urea-N by hyacinths is independent of initial Urea-N concentrations upto a maximum value of 25 mg/l. It is also evident from Fig. 5.1 that removal pattern in all the reactors follow the same trend. Another important feature is speedy removal of Urea-N during day hours between 6 A.M. and 6 P.M. On the other hand, significantly slower uptake of Urea-N is observed at night between 6 P.M. and 6 A.M. Removal efficiency during day hours is approximately 5 times that of preceeding night. The reason of such wide variation in removal efficiency of Urea-N by hyacinths, can be explained on the basis that absorbing cells of the hyacinths roots possess the ability to take up water and nutrients from the external solution. The bulk of water absorbed by the plant through roots is not retained, however, but evaporates in air because of diffusion through stomata, the minute mouth like openings in the surface of leaf. This phenomenona is known as evapotranspiration. Water hyacinth is highly capable of pumping water into the atmosphere via evapotranspiration. The nutrient removal efficiency, therefore, depends upon the magnitude of evapotranspiration. Environmental factors, such as light, temperature and relative humidity cause

the variation in transpiration rate. During the day, as the intensity of the sun's radiation increases, other factors also increases. However, transpiration follows solar radiation more intimately than it does air temperature (Bonner et.al., 1952). So, during night hours (in absence of solar radiation) transpiration rate almost touches zero value which in turn reduces the nutrient removal efficiency to a great extent. Some reduction in Urea-N is also taking place during night hours because of the solar radiation after 6 P.M. and before 6 A.M.

The presence of Ammonia-N was not found in any reactor. But it may not be an evidence for the absence of bacteria, producing urease, because hyacinths are also capable of absorbing Ammonia-N from the feed solution.

(ii) Response of Hyacinths to Ammonia-N:

According to Ramachandran et.al.(1971) ammonia has been used for chemical control of water hyacinths. These studies, therefore, were conducted to explore the possibilities of ammonia toxicity to the hyacinths. Feed solutions containing Ammonia-N concentrations of 10, 15, 20, 25, 30, 50 and 70 mg/l were collected in Reactors 1, 2, 3, 4, 5, 6 and 7 respectively. Fig. 5.2 demonstrates the Ammonia-N reduction pattern in different reactors. Removal patterns in Reactors 1, 2 and 3 were almost same and at 3 days detention time removal efficiencies were about 76 percent in these reactors. In 3 days test period the percent reduction in Ammonia-N was 70 percent in Reactors 4 and 5, and was dropped to 50 percent when initial concentration was 50 mg/l in Reactor 6. The removal efficiency was reduced

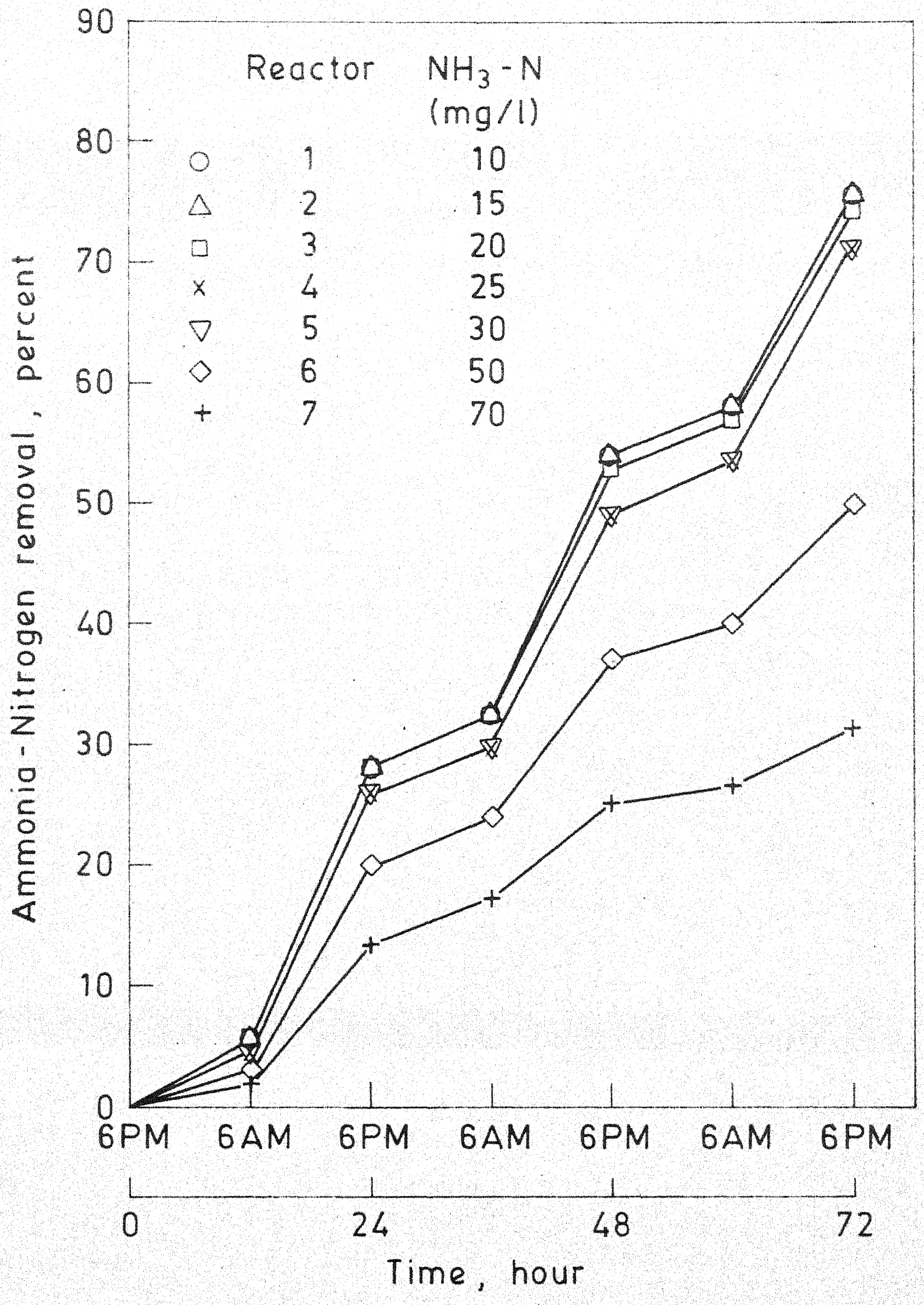

Fig. 5.2 - Response of hyacinths to various concentrations of Ammonia - Nitrogen.

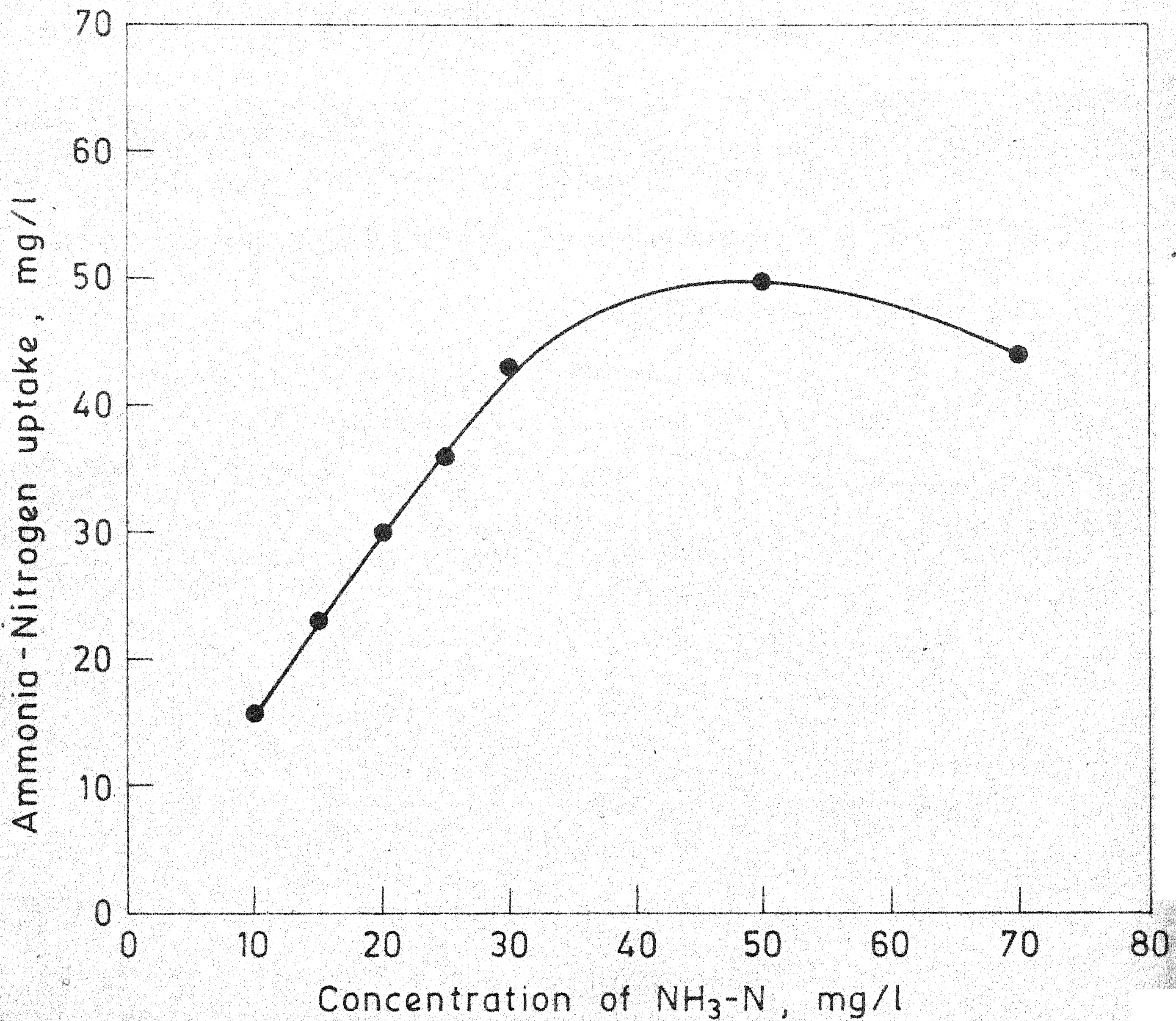

Fig. 5.3 - Variation in ammonia uptake with its different concentrations.

to a great extent (31 percent) when initial concentration of Ammonia-N was 70 mg/l. After 2 days, the plants of Reactors 6 and 7 started turning yellow which indicates the ammonia toxicity to the plants. Fig. 5.3 also shows ammonia toxicity to the plants.

Here, conclusion can be arrived at that the concentration of Ammonia-N higher than 50 mg/l causes toxicity to plants.

(iii) Response of Hyacinths to Nitrate-N:

Fig. 5.4 illustrates the removal pattern of Nitrate-N in Reactors 1, 2, 3 and 4 with initial Nitrate-N concentrations of 10, 15, 20 and 25 mg/l respectively. Removal efficiency of Nitrate-N was observed as about 71 percent upto a concentration of 20 mg/l and 66.5 percent when the initial concentration of Nitrate-N was 25 mg/l. It is also evident from Fig. 5.4 that Nitrate-N uptake pattern for all the reactors is identical.

In summery, the removal efficiency of Nitrate-N because of plants uptake is independent of its initial concentrations upto a certain value of 20 mg/l.

(iv) Response of Hyacinths to Phosphate-P:

Feed solutions containing the concentrations of Phosphate-P as 15, 20, 25 and 30 mg/l were introduced to Reactors 1, 2, 3 and 4 respectively. The uptake pattern of Phosphate-P by hyacinths is shown in Fig. 5.5. This figure indicates that plants give direct response to Phosphate-P upto its initial concentration of 25 mg/l. Plants absorb about 61 percent of Phosphate-P from Reactors 1, 2 and 3 and 58 percent from Reactor 4 at a detention time of 3 days.

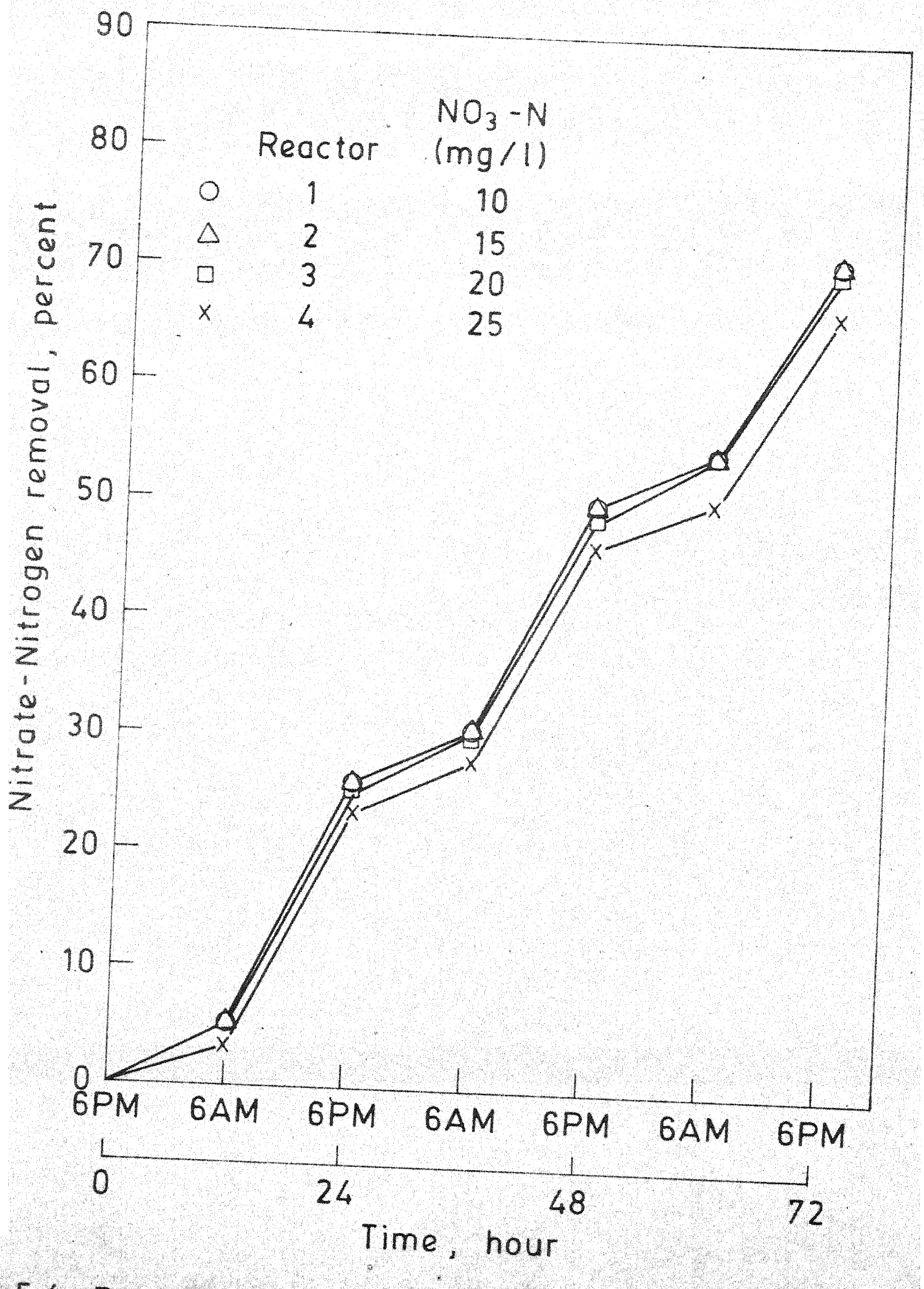

Fig. 5.4 - Response of hyacinths to various concentrations of Nitrate-Nitrogen.

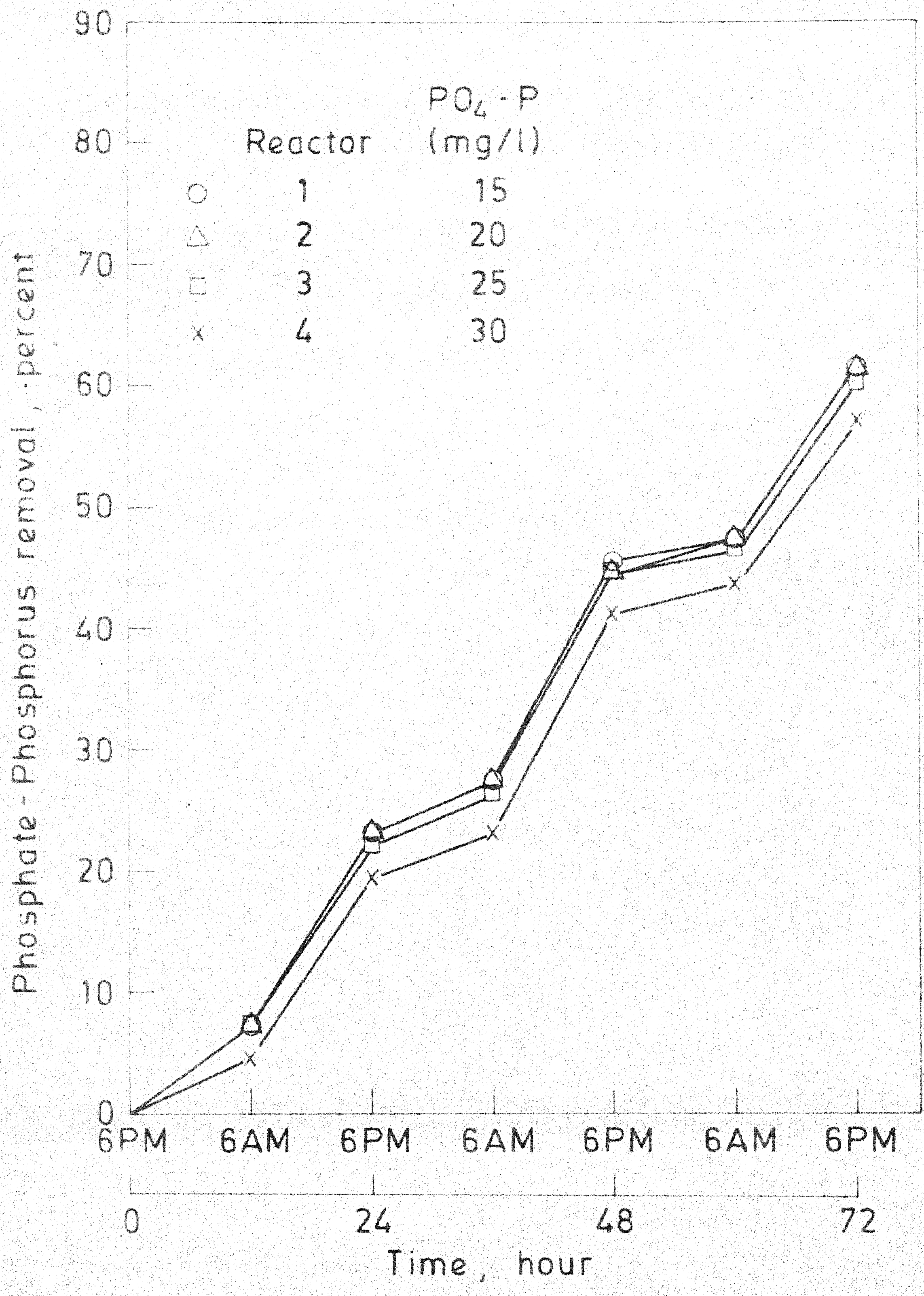

Fig. 5.5 - Response of hyacinths to various concentrations of Phosphate-Phosphorus.

By comparing Figures 5.1, 5.2, 5.4 and 5.5, it can be concluded that Phosphate-P is not removed as rapidly as nitrogen by hyacinths.

5.1.2 Phase 1B Studies:

Ordinarily the conventional secondary wastewater treatment processes result in effluents which contain two to four times as much nitrogen as phosphorous (Grakstatter et.al., 1978). With this impression, therefore, it was decided to evaluate the effect of nitrogen and phosphorous removal efficiencies with different feed N:P ratios. The proportions of each parameters were choosen approximately in accordance with the characteristics of stabilization pond effluent given by Bokil (1968).

The only difference between these experiments and that done in phase 1A was that in this case feed solutions were a mixture of Ammonia-N, Urea-N and Nitrate-N and Phosphate-P and the detention time was 6 days for each of the reactors. The characteristics of feed solutions used in this phase are presented in Table 5.1.

Table 5.1 : Characteristics of feed solutions used in Phase 1B studies

Reactor	COD mg/l	Feed N:P ratio	Ammonia-N mg/l	Urea-N mg/l	Nitrate-N mg/l	Phosphate-N mg/l	pH
1	60	3:1	15	25	5	15	8.5
2	60	3.5:1	25	40	5	20	9.0
3	60	4:1	20	35	5	15	8.0

KANPUR
CENTRAL LIBRARY
A 87477

The degree of treatment achieved with respect to all parameters, viz., Ammonia-N, Urea-N, Nitrate-N and Phosphate-P as well as total nitrogen (Urea-N + NH_3-N + NO_3-N) and phosphorus(PO_4-P) are illustrated in Figures 5.6 to 5.8.

(i) Removal of Urea-N, Ammonia-N, Nitrate-N and Phosphate-P:

The removal pattern of Nitrate-N, Urea-N and Phosphate-P was similar without any appreciable difference in all the reactors as shown in Figures 5.6 to 5.8. Nitrate-N removal efficiencies were 91, 87 and 88 percent in Reactors 1, 2 and 3 respectively after 5 days. These figures also demonstrate that the percent reductions in Urea-N in 5 days were 87, 86 and 84 percent and Phosphate-P removal efficiencies were 83, 84 and 80 percent in Reactors 1, 2 and 3 respectively.

Much difference was noticeable in the trend of Ammonia-N removal in Reactors 1, 2 and 3. Ammonia-N removal efficiencies after 5 days were found to be 72 percent and 81 percent in Reactors 1 and 2 respectively. The corresponding value was 93 percent in Reactor 3. This deviation in the Ammonia-N removal pattern in three reactors might have been due to loss of considerable amount of Ammonia-N by air-stripping as pH was 8.5 and 9.0 in Reactors 1 and 2 respectively. Figures 5.6 and 5.7 illustrate that the amount of Ammonia-N lost from control test, because of air-stripping was 7 percent and 13.5 percent in Reactors 1 and 2 respectively in 6 days. No significant amount of Ammonia-N was lost from Reactor 3 by air-stripping as initial pH was 8.0. The removal efficiency of Ammonia-N was found to be 96 percent in 6 days in this reactor.

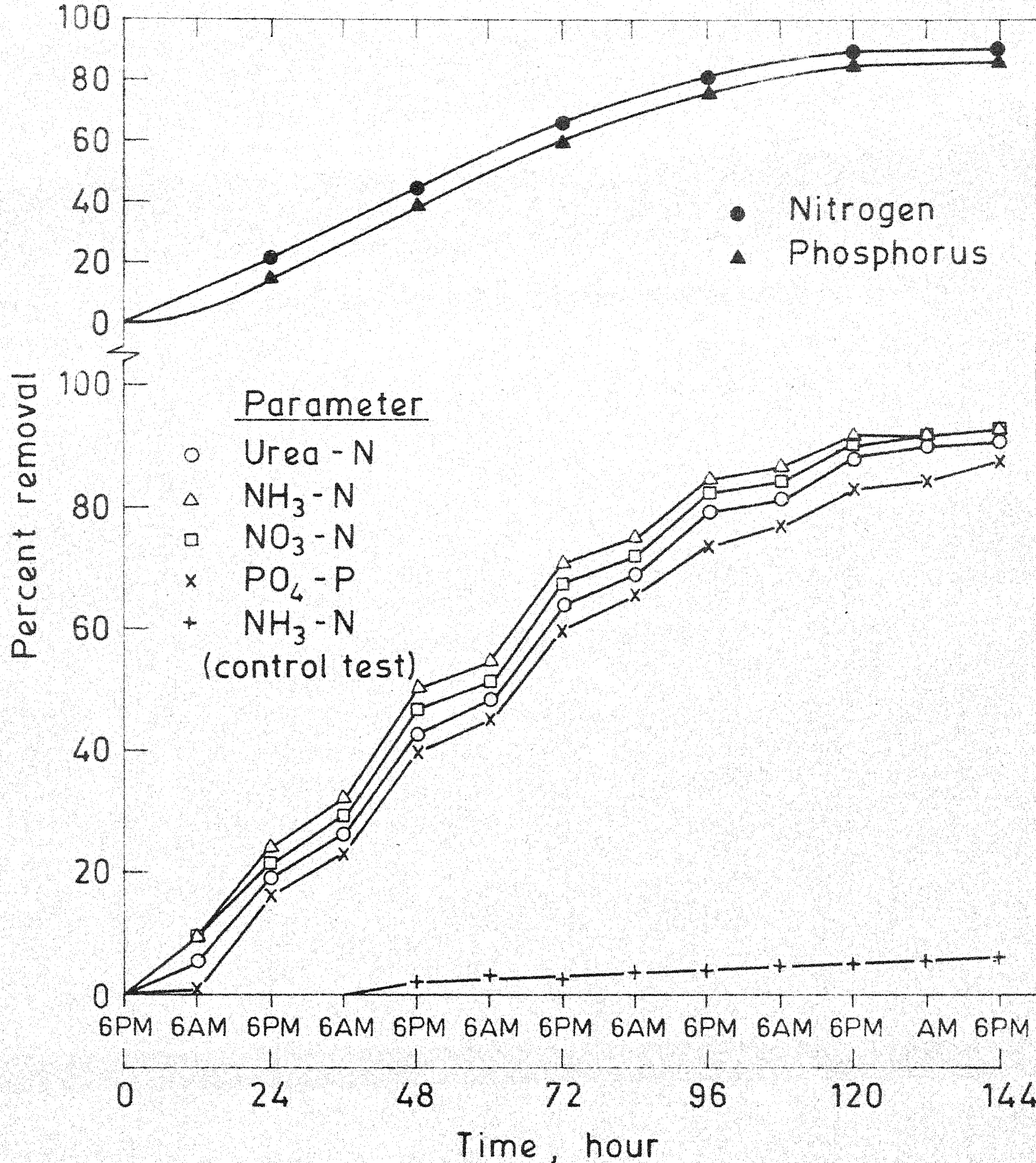

Fig. 5.6 - Removal of nitrogen and phosphorus from feed N:P ratio of 3:1.

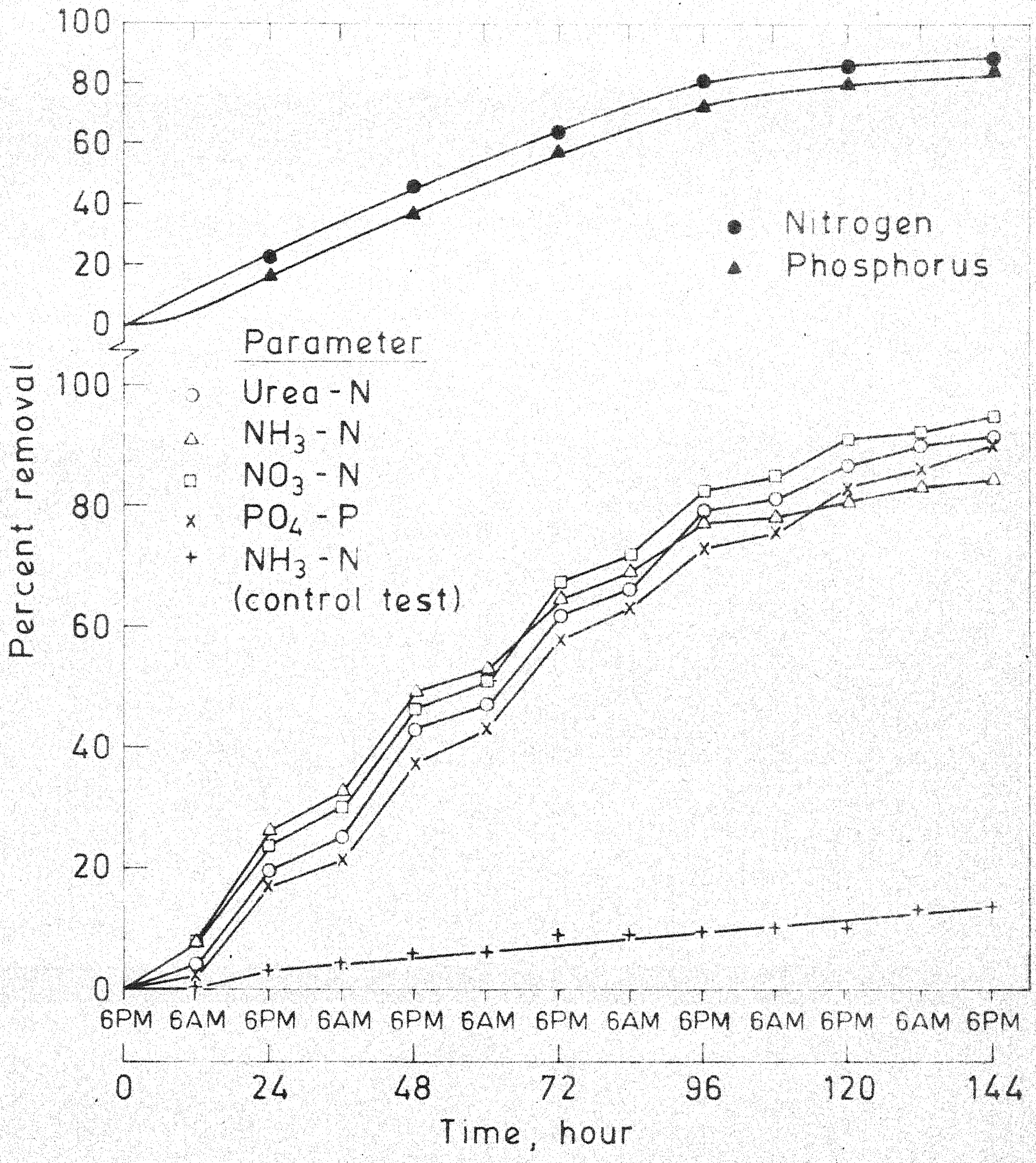

Fig. 5.7- Removal of nitrogen and phosphorus from feed N : P ratio of 3.5 : 1.

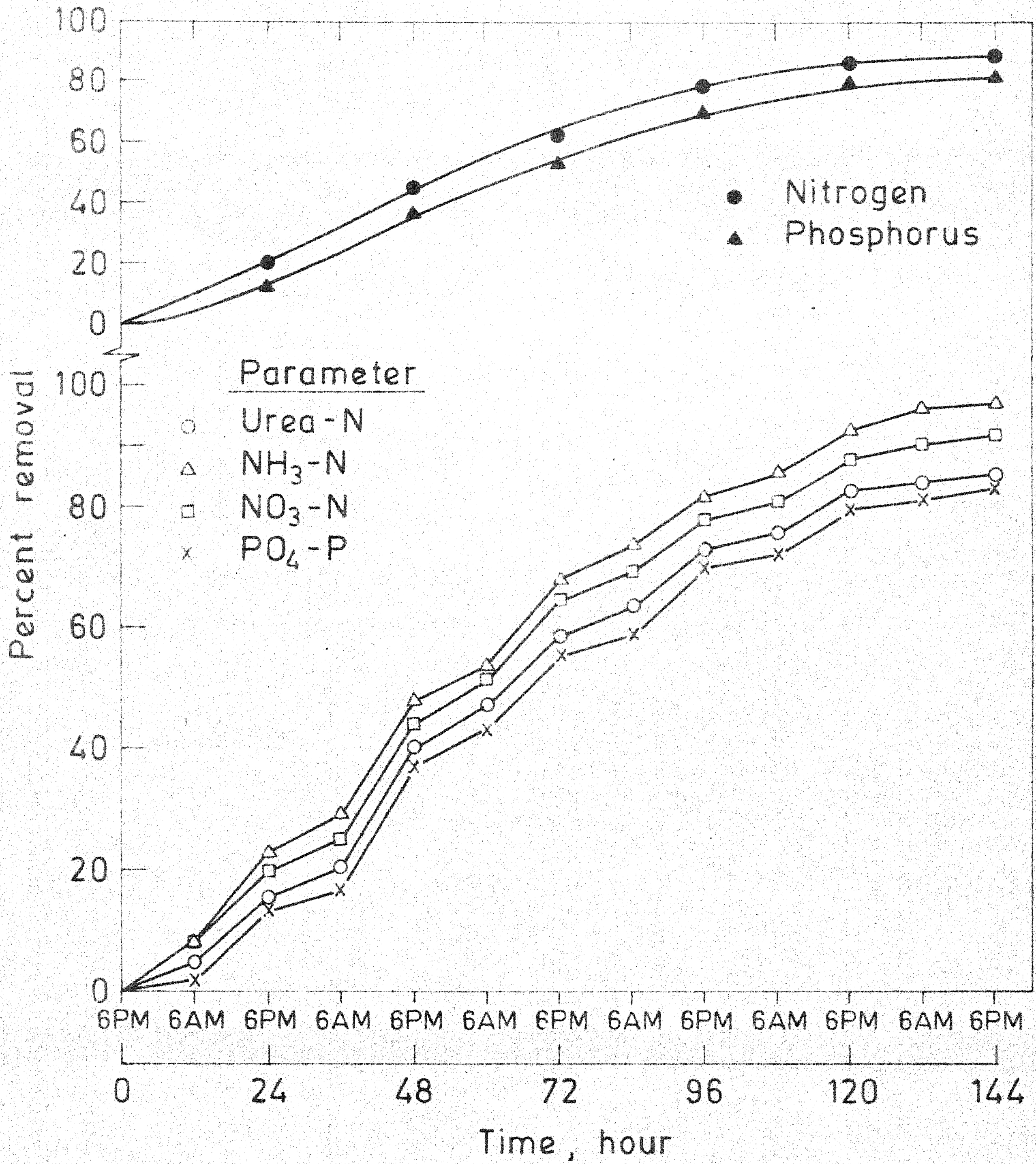

Fig. 5.8 - Removal of nitrogen and phosphorus from feed N : P ratio of 4:1.

Also, the trend of Ammonia-N removal was same as that of all other parameters.

Thus, these results show that although water hyacinth has preference for Ammonia-N, it can still remove relatively large quantities of Nitrate-N, Urea-N and Phosphate-P. The percent removal of these four nutrients at a certain detention time have the following order.

Ammonia-N > Nitrate-N > Urea-N > Phosphate-P .

(ii) Removal of Total Nitrogen (Urea-N + NH_3-N + NO_3-N) and Phosphorous (PO_4-P)

Removal patterns of nitrogen and phosphorous in Reactors 1, 2 and 3 are shown in Figures 5.6, 5.7 and 5.8 respectively. From these figures it can be seen that the removal efficiencies of nitrogen and phosphorous were following more or less the same trend in all the reactors. Yet, another feature can be noted that there is speedy removal of nitrogen and phosphorous for 4 days and thereafter there was almost constant removal. This might be due to the lesser growth rate of plants at lower nutrient levels. The nitrogen removal efficiency at any time was somewhat higher as compared to that of phosphorous. The percent reductions in nitrogen content after 5 days were 88, 86.5 and 87 in Reactors 1, 2 and 3 respectively. The corresponding values of phosphorous were observed as 81.5, 79.5 and 80. The reason of this difference in nitrogen and phosphorous removal is not known.

The variation of nitrogen and phosphorous uptake is shown in Fig. 5.9. This figure indicates that luxury uptake of nitrogen takes place upto a certain period of 4 days in all

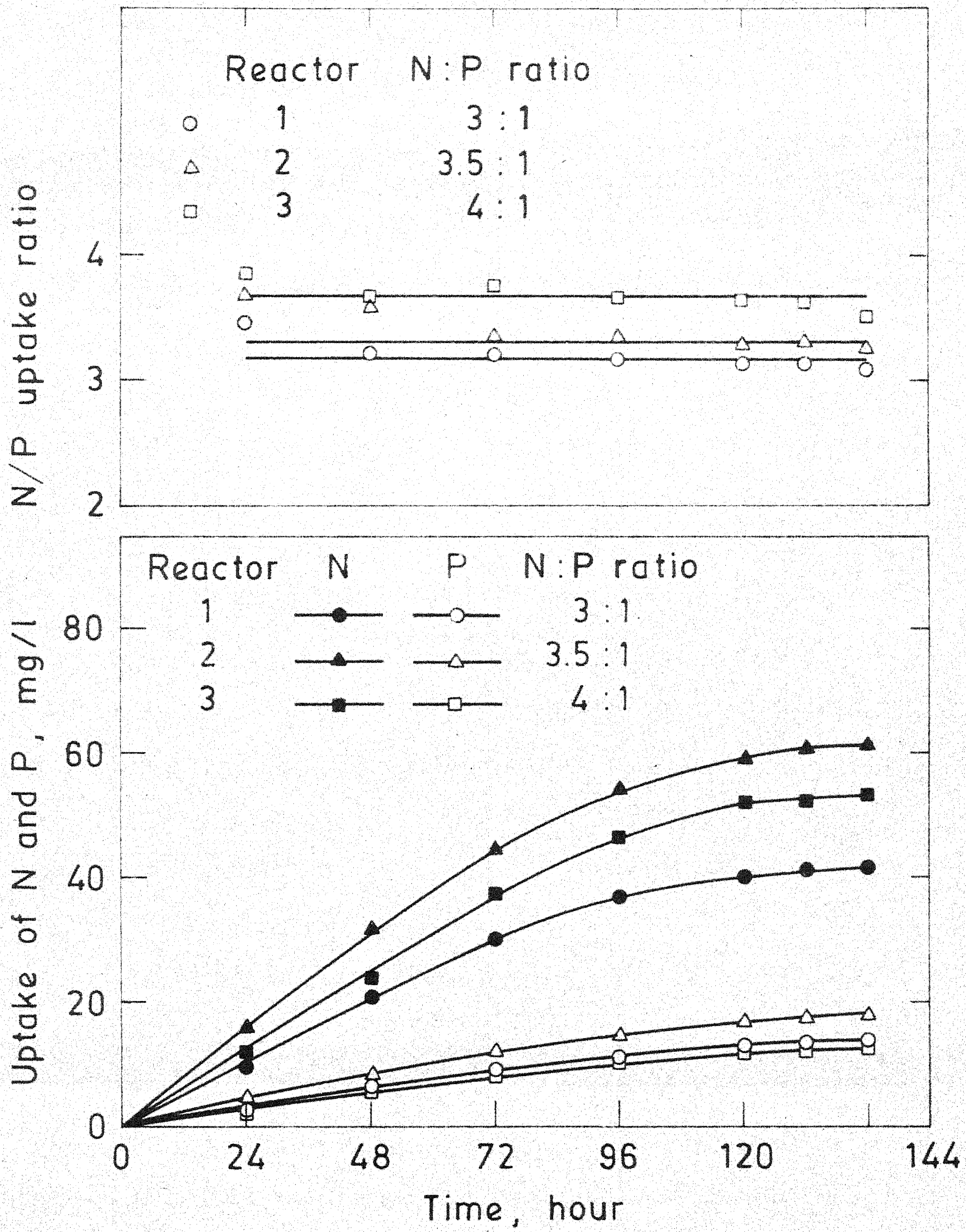

Fig. 5.9 - Temporal variation of nitrogen and phosphorus uptake by hyacinths with various feed N : P ratios.

the three reactors containing feed solutions with N:P ratios of 3:1, 3.5:1 and 4:1 respectively. Nitrogen uptake, observed after 4 days was 36.5, 54 and 46 mg/l in Reactors 1, 2 and 3 respectively. It reveals that nitrogen uptake by water hyacinths increase with the increase in feed nitrogen concentrations. The same behaviour can also be seen for phosphorous uptake.

Fig. 5.9 also demonstrates the N:P uptake ratio for various feed N:P ratios. The average values of N:P uptake ratios are 3.4:1, 3.6:1 and 4.4:1 for Reactors 1, 2 and 3 respectively. It indicates that the N:P uptake ratio depends upon the feed N:P ratio.

The pH values in Reactors 1, 2 and 3 were dropped to 8.1, 8.4 and 7.8 after 6 days from the initial values of 8.5, 9.0 and 8.0 respectively. pH values in control tests for Reactor 1 was reduced to 8.3 and for Reactor 2 was 8.7. No significant reduction was observed in pH value of control test for Reactor 3.

Thus, the above discussion leads to the conclusion that the uptake of nitrogen and phosphorous to a great extent, depends on the nitrogen and phosphorous content of the feed solutions. Further, the nitrogen uptake is 3.4 to 4.4 times more than that of phosphorous.

5.2 Phase 2 Studies:

A hyacinths basin having just sufficient depths to prevent the plant roots from touching the bottom of the basin would possibly be the most efficient in removal of nitrogen and phosphorous. But this much depth of basin does not favour the economy as the length of roots in this study ranged from

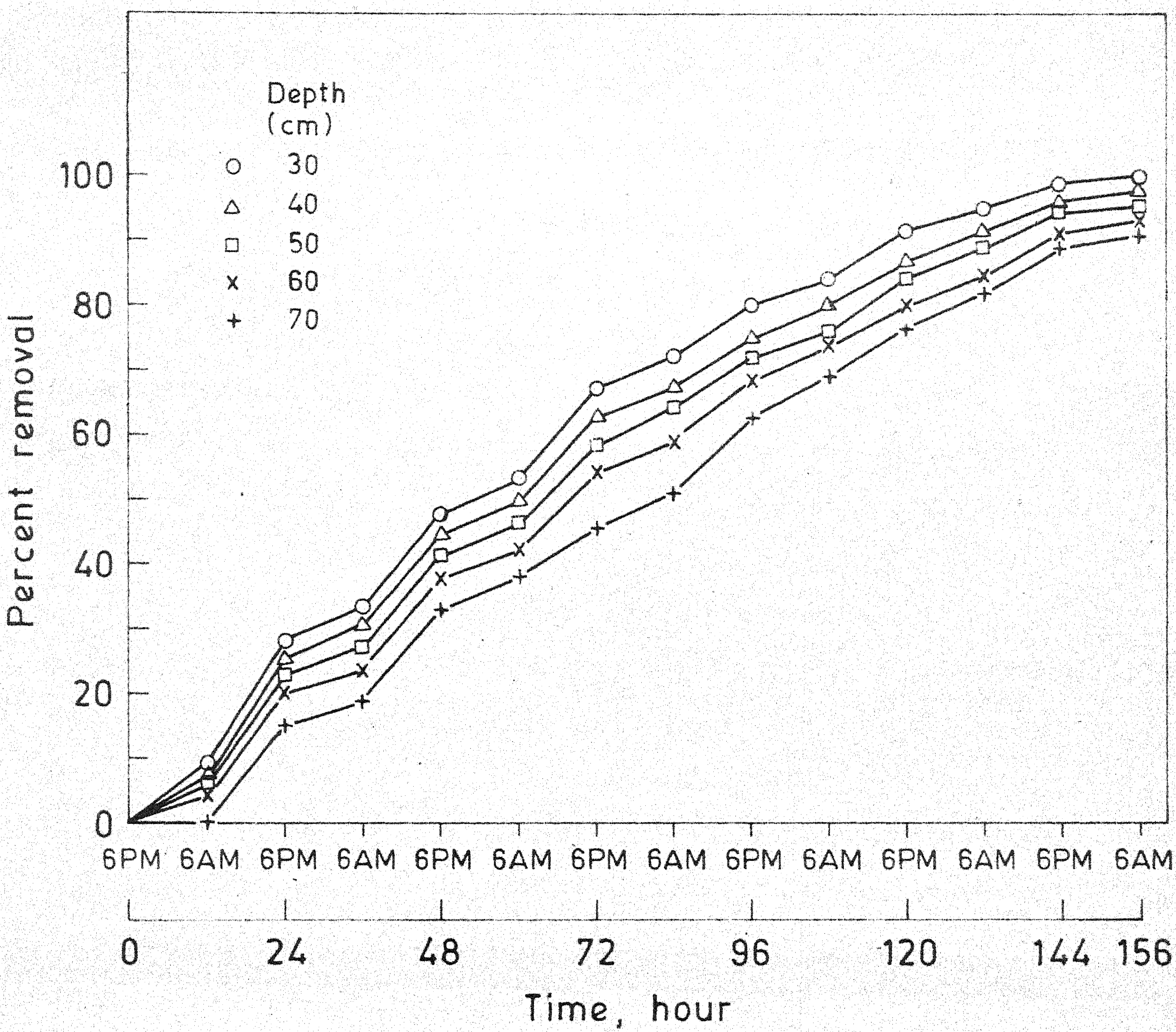

Fig. 5.10 - Removal of phosphorus with various mean operational water depths.

25 to 30 cm only. For an efficient and economical design of hyacinths basin, it was decided, therefore, to evaluate the effect on removal efficiency with varying mean operational water depths of hyacinths basin. To induce the aerobic conditions in hyacinths basin, only 75 percent of plan area of basin was covered with the plants. Regular harvesting of plants was adopted to maintain the constant ratio of 1.33:1 between the surface areas of basin and hyacinth plants.

The feed with N:P ratio of 3.5:1 was used for all the mean operational water depths under consideration. Also, from Phase 1 Studies, it appeared that phosphorous was not removed from feed as rapidly as nitrogen. Thus, the design of the basin with respect to phosphorous removal approaches to a safer side. The variation in removal efficiency of phosphorous for the depths of 30, 40, 50, 60 and 70 cm is illustrated in Fig. 5.10. The removal pattern for all the depths follow the same trend. Detention time for a certain percentage removal, increases with the increase in depths. For example, to achieve 75 percent phosphorous removal, detention times required were 89, 96, 106, 112 and 118.5 hours when depths were 30, 40, 50, 60 and 70 cm respectively. At a detention time of 3 days the removal efficiencies observed were 67.5, 63, 58, 54.5 and 47.5 percent for depths of 30, 40, 50, 60 and 70 cm respectively.

In conclusion, the nutrient removal capability of hyacinths is related to the mean operational water depth of hyacinths basin.

5.3 Phase 3 Studies:

The ultimate objective of any theoretical or experimental work is to suggest process modification and/or rational design criteria for the unit operation under consideration. In this phase of the study, an optimum design criteria is developed for the removal of nitrogen and phosphorous from secondary effluents with water hyacinth culture, utilizing the results obtained from the experimental investigation of the present study.

The optimum design of the process involves the determination of decision variables (design variables) so that the specified objective function is optimized. In the present case the cost of the hyacinthsbasin is taken as an objective function to be minimized. It involves the cost of land required, earth excavation and lining. Mathematically the problem can be stated as:

$$\text{Find the design vector } x = \begin{bmatrix} N \\ L \\ B \\ D \end{bmatrix}$$

which minimizes the objective function (cost function).

$$F(x) = N\left[c_1 \text{ (land area)} + c_2 \text{ (earth excavation)} + c_3 \text{ (lining)}\right] \qquad (5.1)$$

subject to certain behavioural and geometric constraints.

where,

N is the number of units;

L, B, D are the length, width and mean operational water depth of hyacinths basin respectively;

c_1 is the cost of land (Rs/m^2);

c_2 is the cost of excavation (Rs/m^3);

and c_3 is the cost of lining (Rs/m^2).

The major process parameter which controls the design variables is the detention time which in turn depends on several factors such as depth of the basin, characteristics of the waste, environmental conditions, latitude etc. Among these factors, a designer, in general can control only the depth of the hyacinths basin. From the experimental investigation (Section 5.2) it is clear that the detention time required to achieve a certain percentage removal of a particular pollutant depends upon the depth of the basin. Further the detention time required to reduce the load of different nutrients by same percentage is different. In the present study the removal of four different nutrients viz., Urea-N, Ammonia-N, Nitrate-N and Phosphate-P was studied and it was found that the detention time required to achieve the same percentage removal of these nutrients had the following order.

$$T_{PO_4-P} > T_{Urea-N} > T_{NO_3-N} > T_{NH_3-N}$$

where, T_{PO_4-P}, T_{Urea-N}, T_{NO_3-N} and T_{NH_3-N} are the detention times required for the same percentage removal of Phosphate-P, Urea-N, Nitrate-N and Ammonia-N respectively.

This indicates that the removal of phosphorous is minimum and hence the overall detention time will be controlled by the desired percentage removal of phosphorous. Further, as stated earlier the detention time required depends upon the depth of the basin and hence it is necessary to obtain a relationship

between the required detention time and depth. Because of the lack of knowledge of the exact removal mechanism a theoretical quantitative relation between these two parameters is not possible and hence an empirical approach is adopted. From the Fig. 5.11 it is clear that the detention time t_R required to achieve certain percentage removal increases with the increase in depth. After noting the observed nature of the variation of t_R with depth, the following expression is proposed.

$$t_{R_D} = t_{R_{D_o}} e^{K(D - D_o)} \qquad (5.2)$$

where,

D is any mean operational water depth, D;

D_o is reference mean operational water depth (= 30 cm);

t_{R_D} is the detention time required for certain percentage removal of phosphate-P at depth, D;

$t_{R_{D_o}}$ is detention time required for same percentage removal of phosphate-P at reference depth, D_o;

and K is a constant (cm^{-1}).

Morquardt (BSOLVE REGRESSION ALGORITHM) is used to solve the coefficients in multi variable non-linear regression equation (Kuester et.al., 1973). This algorithm employes least square objective function for minimization. A very good correlation is obtained between the experimental (Fig. 5.11) and model predicted values. The computed values of the constant K along with the values of coefficient of correlation R and standard error of estimate S, are presented in Table 5.2. The

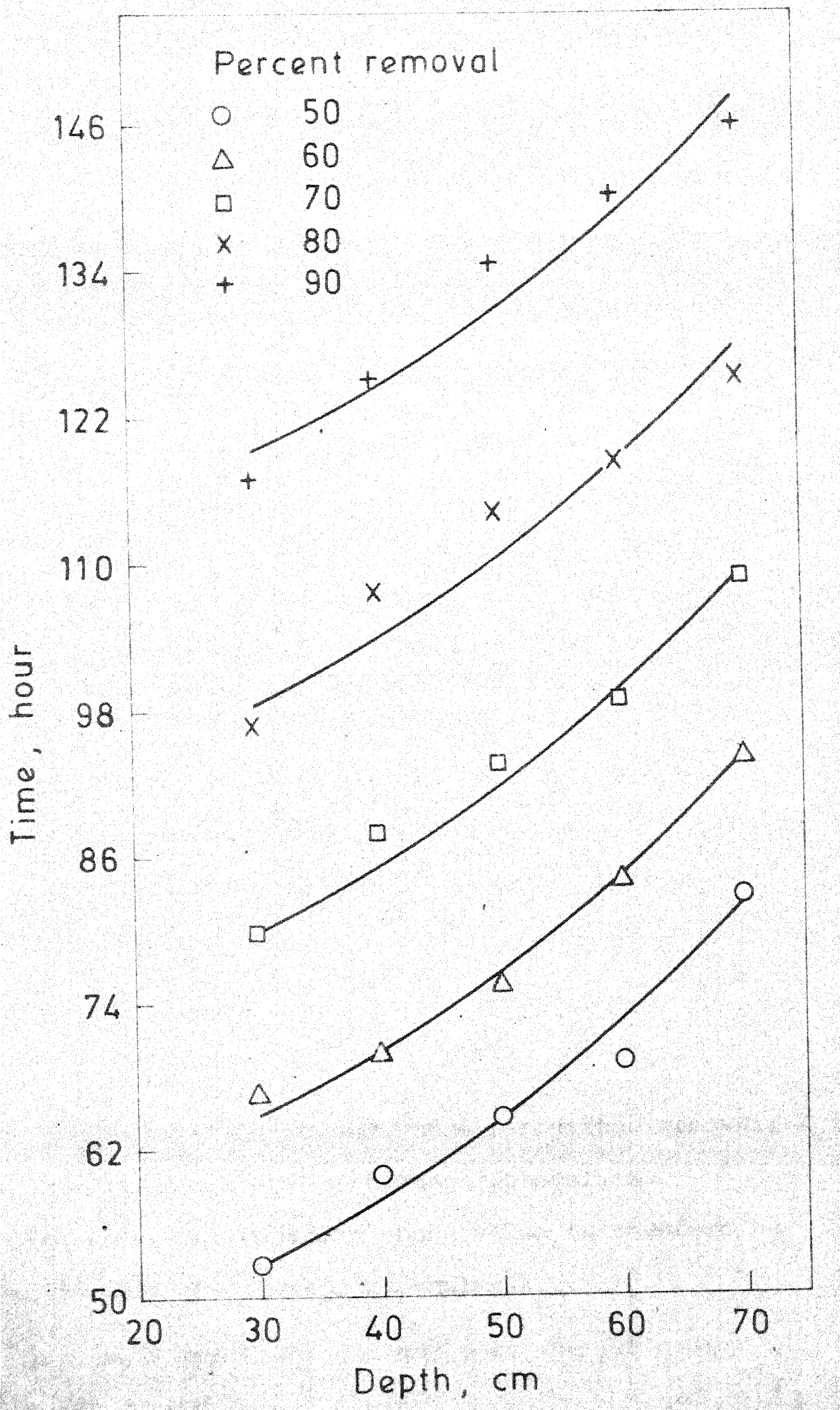

Fig. 5.11- Variation in detention time with different mean operational water depths for certain percent removal of phosphorus

very low values of R and S approaching to unity indicate the validity of the relation proposed in Eq. (5.2).

Table 5.2 : Computed values of K, R and S

Percentage removal	K (cm^{-1})	R	S
50	0.109×10^{-1}	0.998	1.01
60	0.908×10^{-2}	0.989	1.06
70	0.764×10^{-2}	0.987	1.21
80	0.650×10^{-2}	0.997	1.33
90	0.538×10^{-2}	0.995	1.52

From Table 5.2 it can be observed that the value of K decreases with the increase in percentage removal. To predict the value of K for different percentage removal following relationship is proposed.

$$K = K_R . e^{-m(X-X_R)} \tag{5.3}$$

where,

K_R is the value of K for reference percentage removal, X_R;

K is any value for any percentage removal, X;

and m is an empirical constant whose value is found to be 0.0176 from the regression analysis.

Combining Eqs. (5.2) and (5.3) one may work the following relationship for t_R and X_R

$$t_{R_D} = t_{R_{D_o}} e^{[(K_R e^{-m(X-X_R)})(D-D_o)]} \qquad (5.4)$$

Now, objective function

$$F(x) = N[c_1(\text{land area}) + c_2(\text{earth excavation}) + c_3(\text{lining})]$$

Let the length and width of basin to be equal

So, plan area of basin, $A = B^2$

Therefore,

$$F(x) = N[c_1(\frac{Q.t_{R_D}}{D}) + c_2(Q.t_{R_D}) + c_3\{\frac{Q.t_{R_D}}{D} + 4(Q.t_{R_D}.D)^{\frac{1}{2}}\}]$$

Here,

Q is incoming flow rate (m^3/day) of secondary effluent.

or,

$$F(x) = N[Q.t_{R_D}(\frac{c_1}{D} + c_2 + \frac{c_3}{D}) + 4c_3(Q.t_{R_D}.D)^{\frac{1}{2}}]$$

Now, substituting the value of t_{R_D} from Eq. (5.4) in the objective function,

$$F(x) = N[Q.t_{R_{D_o}}(\frac{c_1}{D} + \frac{c_3}{D} + c_2).e^{K_R(D-D_o).e^{-m(X-X_R)}}$$

$$+ 4c_3\{DQ.t_{R_{D_o}}.e^{K_R(D-D_o).e^{-m(X-X_R)}}\}^{\frac{1}{2}}]$$

Thus, to get the optimum value of the above function with respect to mean operational water depth, D, one may work

$$\frac{d\ F(x)}{dD} = 0$$

$$\frac{d\ F(x)}{dD} = N\ [\ Q(c_1+c_3)e^{-m(X-X_R)}\ K_R.\ e^{K_R(D-D_o).e^{-m(X-X_R)}}$$

$$(\frac{1}{D} - \frac{1}{D^2 K_R.e^{-m(X-X_R)}} + \frac{c_2}{c_1+c_3}) + 2c_3(Q.t_{R_{Do}}.$$

$$e^{K_R(D-D_o).e^{-m(X-X_R)}})^{1/2}\ (D^{1/2}.K_R.e^{-m(X-X_R)} + \frac{1}{D^{1/2}}\ )\ ]=0 \tag{5.5}$$

By putting the values of c_1=Rs.60 per m^2, c_2=Rs.3 per m^3, N=1, c_3=Rs. 12 per m^2, t_{RD_o}= 5 days, K_R=1.09 m^{-1}, X_R=50 percent, X=90 percent, m = 0.0176, and D_o=0.3 m in Eq. (5.5). The value of D was obtained as 1.702 to 1.717 m for different values of Q (see Appendix). Actually speaking, this optimum value of depth does not depend upon the flow rate, Q, as clear from appendix, there is no noticeable difference in D values for wide range of flow rates. For more clarity, if hyacinths basin is not lined, Q does not come at all in the expression of $\frac{d\ F(x)}{dD}$. And it is obvious too, that lining in the basin will not cause any influence on the removal mechanism.

Therefore, one can adopt 1.7 m as optimum mean operational water depth of hyacinths basin. Total depth of basin can be set as 2 m including free board of 30 cm. Detention time required for 90 percent removal of phosphorous with the depth of 1.7 m, can be worked out from Eq. (5.4). This value comes out to be 11.5 days. As stated earlier in Section 5.2, only 75 percent surface area of experimental hyacinths basin was covered with the plants. So, it leads the conclusion that water hyacinths can remove 90 percent phosphorous from the basin with an optimum

mean operational water depth of 1.7 m, at a detention time of 11.5 days when a ratio of 1.33:1, between the surface areas of basin and hyacinth plants is kept constant.

Hence, in designing a nutrient removal system with water hyacinths, when the depth and detention time are once set, the surface area required for a known value of flow rate can be estimated by mathematical computation.

5.3.1 Harvesting of Hyacinths:

As oxygen produced by the plants in photosynthesis might not be significantly contributed to the oxidation process occurring within the basin, the anaerobic portion of basin, if any, may increase and, under conditions of heavy BOD loading, become total. Although water hyacinths are not affected by these conditions, odour problems may result (Wolverton _et_._al_., 1979). These problems may become worst in the basin, with complete coverage of hyacinths, during photosynthetically inactive periods.

It is necessary, therefore, to have regular and rotational harvesting of plants and keeping only three-fourth of basin area covered with hyacinths to allow sufficient natural aeration facilities. Although the necessity of periodic harvesting of hyacinths adds to the cost of operation of the system, but one can be optimistic over the prospect of selling the harvested plants to recover at least a part of harvesting cost. Hyacinth plants, as stated earlier, can be used for cattle feed, plant compost and biogas production etc. The layout of the whole scheme of hyacinths system is demonstrated in Fig. 5.12.

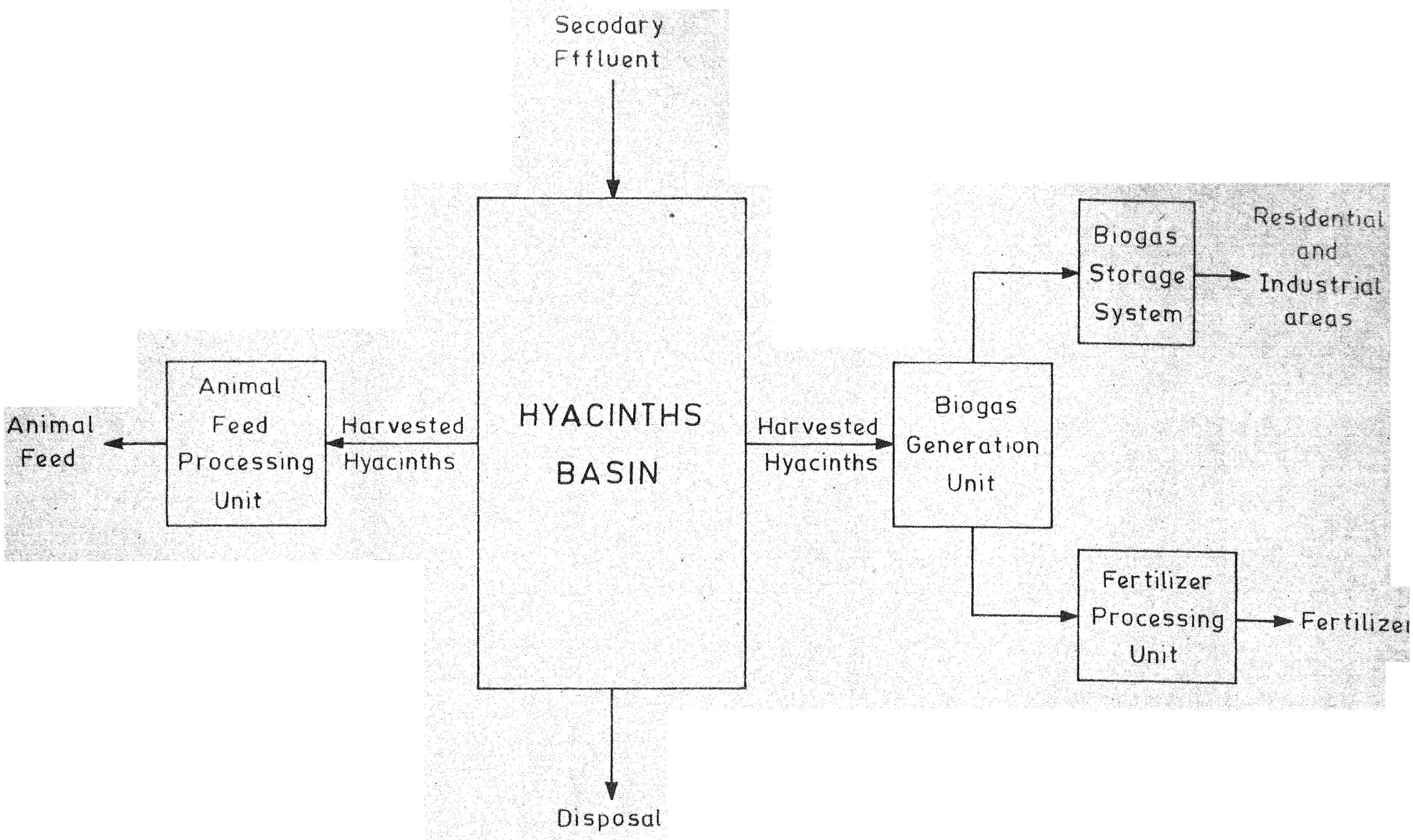

Fig. 12- A model system for secondary effluent treatment using water hyacinth and subsequent utilization of harvested hyacinth plants.

5.3.2 Limitations of the Proposed Hyacinths System:

The actual hyacinth basins in the field can be subjected to many environmental as well as geographical factors that may modify the processes in the basins. These can be grouped briefly as:

(a) Effect, if any, of the growth of other weeds and similar plants

(b) Effect of the variation in latitude and temperature. (According to Oswald et.al. (1957) solar radiation falling on the ground is a function of latitude and month).

Thus, for designing the hyacinths system in the field, it is necessary to state that empirical relationships, proposed in the present study should be modified with respect to above mentioned factors. Also, the variations in cost of land, earth excavation and lining, taken from the specifications reported by Dutta (1980), may vary from place to place, and hence it should be accounted.

6. CONCLUSIONS

On the basis of the findings of the current study, following conclusions can be arrived at:

(1) Removal efficiencies of Urea-N, Ammonia-N, Nitrate-N and Phosphate-P are almost independent of their feed concentration upto the value of 25, 20, 20 and 25 mg/l respectively.

(2) Although water hyacinths have preference for Ammonia-N upto its feed concentration of 25 mg/l, it can still remove relatively large quantities of NO_3-N, Urea-N and PO_4-P. Further, the detention time (T) required to achieve the same percentage removal of these parameters have order

$$T_{PO_4-P} > T_{Urea-N} > T_{NO_3-N} > T_{NH_3-N}$$

Any feed NH_3-N concentration higher than 50 mg/l gives toxic effects to the plants.

(3) Removal pattern for each parameter follows the same trend. Also, the removal efficiency of each parameter is approximately 5 times higher during day hours than that of preceeding night.

(4) Total nitrogen (Urea-N + NH_3-N + NO_3-N) uptake by hyacinths is 3.4 to 4.4 times more than that of phosphorous (PO_4-P) for various feed N:P ratios of 3:1, 3.5:1 and 4:1.

(5) Phosphorous uptake decreases with increase in mean operational water depth of hyacinths basin. Detention time required for a certain percentage of phosphorous removal with different mean operational water depths varies in accordance with the equation

$$T_{R_D} = T_{R_{D_o}} e^{K(D-D_o)}$$

where T_{R_D} is the detention time required for certain percentage removal of phosphorous at any mean operational water depth, D; $T_{R_{D_o}}$ is the detention time required for the same phosphorous percent removal at reference mean operational water depth, D_o; and K is a constant (cm^{-1}) which varies with the extent of percent phosphorous removal and follows the relation

$$K = K_R^{-m(X-X_o)}$$

in accordance with experimental data.

where, K_R is the value of K for reference percentage removal, X_R (= 50%); K is the value of K for any percentage removal, X; and m is an empirical constant with a value of 0.0176.

(6) Water hyacinths can remove 90 percent phosphorous from the basin with optimum mean operational water depth of 1.7 m, at a detention time of 11.5 days when the ratio of 1.33:1, between the plan surface areas of the basin and hyacinth plants, is kept constant.

(7) Precise definition of optimal hyacinths basin design can only be estimated by extensive observations of experimental system.

7. RECOMMENDATIONS FOR FUTURE RESEARCH

On the basis of the results of present investigation, it is felt that further work should be undertaken in the following areas:

(1) To be more realistic the empirical relations should be fitted for more number of observations with varying depths. This warrents further experimental studies using more depths.

(2) Continuous studies after such batch studies are essential for verification of the performance of water hyacinths system.

(3) Field studies should be carried out to supplement the current work.

(4) Studies are still required so as to clarify and explain the nature of removal mechanisms more precisely.

REFERENCES

Betzer, N., Argamen, Y., and Kott, Y. (1980). Effluent Treatment and Algae Recovery by Ozone Induced Floatation. Water Res., 14:1003.

Bhalerao, B.B., and Alagarswamy, S.R. (1973). Treatment Alternatives and Cost Studies for Liquid Effluents in Fertiliser Industry. Indian J. Env. Health, 15:329.

Bhattacharrya, S.H., Bhattacharrya, G.S., and Dutta, B.K. (1973). Removal of Nitrogen from Nitrogeneous Effluents. Technology, 10:321.

Biswas, K., and Calder, C.C. (1954). Eradiction of Water Hyacinth. Handbook of Common Water and Marsh Plants of India and Burma, Govt. Press, New Delhi and Calcutta, 24. Cited in Gopal, B., and Sharma, K.P. (1981). Distribution. Water Hyacinth (Eichhornia crassipes), Rashtravani Printers, Mayapuri, New Delhi, 8.

Bock, J.H. (1969). Productivity of the Water Hyacinth, Eichhornia crassipes (Mart.) Solms. Ecology, 50:460.

Bokil, S.D. (1968). Stratification in Oxidation Ponds. M.Tech. Thesis. Indian Institute of Technology, Kanpur.

Bonner, J., and Galston, A.W. (1952). Environmental Factors and Transpiration. Principles of Plant Physiology, Freeman and Co., San Francisco, 105.

Charbit, G.E. (1966). Reagent for the Determination of Urea in Different Liquids. Chemical Abstracts, 65:17356.

Corwell, D.A., Zolter, J., Patrinely, C.D., Furman, T.S., and Kim, J.I. (1977). Nutrient Removal by Water Hyacinths. J. Water Poll. Cont. Fed., 49:57.

Cousins, W.G., and Mindler, A.P. (1972). Tertiary Treatment of Urea Ammonia Liquor. J. Water Poll. Cont. Fed., 44:607.

Culp, R.L., Wesner, G.M., and Culp, G.L. (1978). Nitrogen Removal. Handbook of Advanced Wastewater Treatment, 2nd Edn., Van Nostrand Reinhold Co., New York, 298.

Dinges, R. (1976). Who Says Treatment Plants Have to be Ugly. Water Waste Engg., 13:20.

Dinges, R. (1978). Upgrading Stabilization Pond Effluent by Water Hyacinth Culture. J. Water Poll. Cont. Fed., 50:833.

Dunigan, E.P., Shamsuddin, Z.H., and Phelan, R.A. (1975). Can Water Hyacinth Eat Pollution? Compost Sci., 16:11.

Dutta, R.K., Chakrabarty, P.R., Guha, B.C., and Ghosh, J.J. (1966). Studies on Leaf Protein: Preparation of Protein Concentrate from Leaves of Water Hyacinth. Science Cult., 32:247.

Dutta, B.N. (1980). Estimating and Costing in Civil Engineering. 14th Edn., Dutta and Co., Lucknow.

Evans, A.C. (1963). The Grip of Water Hyacinth. New Scientist, 19:666.

Gakstatter, J.H., Allum, M.O., Dominguez, S.E., and Crouse, M.R. (1978). A Survey of Nitrogen and Phosphorous Levels in Treated Municipal Wastewater. J. Water Poll. Cont. Fed., 50:718.

Gates, W.E., and Borchardt, J.A. (1964). Nitrogen and Phosphorous Extraction from Domestic Wastewater Treatment Plant Effluents by Controlled Algal Cultures. J. Water Poll. Cont. Fed., 36:443.

Gopal, B., and Sharma, K.P. (1981). Water Hyacinth (Eichhornia crassipes). Rastravani Printers, Mayapuri, New Delhi.

Haug, R.T., and McCarty, P.L. (1972). Nitrification with Submerged Filters. J. Water Poll. Cont. Fed., 44:2086.

Holm, L.G., Weldon, L.W., and Blackburn, R.D. (1969). Aquatic Weeds. Science, 166:699.

Jatkar, D.D. (1981). Paper from Troublesome Hyacinth. Business India, 90:37.

Kuester, J.L., and Mize, J.H. (1973). Optimization Techniques with Fortran, McGraw-Hill, New York.

Lackey, J.B. (1958). Effect of Fertilization on Receiving Waters. Sewage and Ind. Wastes, 30:1411.

Mercer, B.M., Ames, L.L., Tonbill, C.J., Vanslyke, W.J., and Dean, R.B. (1970). Ammonia Removal from Secondary Effluents by Selective Ion Exchange. J. Water Poll. Cont. Fed., 42:95.

Metcalf and Eddy Inc. (1979). Wastewater Engineering: Treatment, Disposal, Reuse. 2nd Edn., Tata McGraw-Hill Publishing Co. Ltd., New Delhi.

Michel, H.L., Gilbert, P.H., and Creed, H.K. (1974). Land Disposal - What's the Realistic View? Water and Wastes Engg., 11:30.

Oswald, W.J., and Cotass, H.B. (1957). Photosynthesis in Sewage Treatment. Trans. Am. Soc. Civil Eng., 73:122.

Parija, P. (1934). Physiological Investigations on Water Hyacinth in Orissa with Notes on Some Other Aquatic Weeds. Indian J. Agric. Sci., 4:399. Cited in Gopal, B., and Sharma, K.P. (1981). Effect of pH. Water Hyacinth (Eichhornia crassipes), Rastravani Printers, Mayapuri, New Delhi, 57.

Pirie, N.W. (1966). Leaf Protein as a Human Food. Science, 152:1701.

Ramachandran, V., Ramabrabhu, T., and Reddy, P.V.G.K. (1971). Eradication and Utilisation of Water Hyacinth (E. crassipes). Curr. Sci., 40:367.

Sharma, A. (1971). Eradication and Utilisation of Water Hyacinth — A Review. Curr. Sci., 40:51.

Sriramulu, N., and Bhargava, B.N. (1980). Biogas from Water Hyacinth. Research Project, Nagarjunasagar Engg. College, Hyderabad.

Standard Methods for the Examination of Water and Wastewater (1965). 12th Edn., American Public Health Association, Inc., New York.

Stewart, B.A. (1968). Agriculture's Effect on Nitrate Pollution on Ground Water. J. Soil and Water Cons., 13:23.

Warton, D.C., and McCarty, E. (1972). Experiments and Methods in Biochemistry. Macmillan, New York.

Weert, R.V., and Kamerlung, G.E. (1974). Evapotranspiration of Water Hyacinth (Eichhornia crassipes). J. Hydrology, 22:201.

Wolmann, A. (1977). Public Health Aspects of Land Utilisation of Wastewater Effluents and Sludges. J. Water Poll. Cont. Fed., 49:2211.

Wolverton, B.C. (1975a). Water Hyacinths for Removal of Cadmium and Nickel from Polluted Waters. NASA Technical Memorandum TM-X-72721, Washington, D.C.

Wolverton, B.C., and McDonald, R.C. (1975b). Water Hyacinths and Alligator Weeds for Removal of Lead and Mercury from Polluted Waters. NASA Technical Memorandum TM-X-72723, Washington, D.C.

Wolverton, B.C., Barlow, R.M., and McDonald, R.C. (1975c). Application of Vascular Aquatic Plants for Pollution Removal, Energy, and Food Production in a Biological System. NASA Technical Memorandum TM-X-72726, Washington, D.C.

Wolverton, B.C., and McDonald, R.C. (1975d). Water Hyacinths and Alligator Weeds for Removal of Silver, Cobalt, and Strontium from Polluted Waters. NASA Technical Memorandum TM-X-72727, Washington, D.C.

Wolverton, B.C., McDonald, R.C., and Gordon, J. (1975e). Bio-Conversion of Water Hyacinths into Methane Gas: Part I. NASA Technical Memorandum TM-X-72725, Washington, D.C.

Wolverton, B.C., and McDonald, R.C. (1976a). Don't Waste Water Weeds. New Scientist, 72:1021.

Wolverton, B.C., and McDonald, R.C. (1976b). Water Hyacinths for Upgrading Sewage Lagoons to Meet Advanced Wastewater Treatment Standards: Part II. NASA Technical Memorandum TM-X-72735, Washington, D.C.

Wolverton, B.C., and McDonald, R.C. (1979). Upgrading Facultative Wastewater Lagoons with Vascular Aquatic Plants. J. Water Poll. Cont. Fed., 51:305.

Youg, J.C., Baumann, E.R., and Dannyal, V. (1975). Packed Bed Reactors for Secondary Effluent BOD and Ammonia Removal. J. Water Poll. Cont. Fed., 47:46.

APPENDIX

VALUES OF MEAN OPERATIONAL WATER DEPTH FOR DIFFERENT FLOW RATE (Q) VALUES

Flow rate, Q (m^3/day)	Mean operational water depth, D (m)	Derivative
500	1.701	-75.438
500	1.702	8.057
600	1.704	-58.071
600	1.705	40.691
700	1.706	-80.094
700	1.707	35.958
800	1.708	-51.162
800	1.709	81.096
900	1.709	-118.242
900	1.710	30-322
1000	1.710	-153.259
1000	1.711	1.564
1100	1.712	-3.467
1100	1.713	117.155
1200	1.712	-181.447
1200	1.713	15.772
1300	1.713	-152.462
1300	1.714	60.558
1400	1.714	-97.305
1400	1.715	132.149
1500	1.715	-15.126
1500	1.716	230.299
1600	1.716	-120.238
1600	1.717	15.247

A 87477

CE-1981-M-BAN-NUT